

**To:** Jill Komoto  
  
Lummi Natural Resources Department  
2665 Kwina Road  
Bellingham, WA 98226

**From:** Natural Systems Design

**Date:** May 18, 2016

**Re:** Porter Creek Reach – Phase 1 and 4 Final Basis of Design Report

## PROJECT BACKGROUND

The Lummi Natural Resources Department (LNRD) and Nooksack Salmon Enhancement Association (NSEA) have identified the Lower Middle Fork Nooksack River (Middle Fork) near Porter Creek as a candidate location for habitat restoration. The proposed restoration reach is between river mile RM 4.9 (upstream end) and RM 4.6 (downstream end) (Figure 1). This reach was targeted by NSEA for restoration following the recommendations put forth in the WRIA I Recovery Plan (WRIA 1 2005) for the entire Middle Fork, and the geomorphic and hydraulic assessment conducted by Natural Systems Design (NSD, 2013).

## Restoration Goals

The specific restoration goals and metrics for the project reach include:

RESTOARTION GOAL NUMBER	PROJECT GOAL	PROJECT METRIC
1	Improve long-term channel stability	Reduce average channel velocities by 1-2 ft/s during the 10-year peak flow
2	Promote the formation and growth of forested islands and associated side channels	Create 23 stable flow separation zones that riparian and forest vegetation can establish in the lee of
3	Increase key habitat quantity and quality through primary pool creation	Create 3 primary and 6 secondary pool habitat units
4	Increase the frequency of stable spawning habitat	Create 8 stable flow separation zone to sort sediments more appropriate for spawning
5	Stabilize naturally occurring accumulations of unstable large wood within the reach	Create 23 stable hard points that mobile wood can rack on during flows greater that the 1-year peak flow
6	Increase floodplain and side channel connectivity.	Raise average channel flow depths 0.5-1.0 ft during the 10-year peak flow
7	Protect/enhance floodplain tributary habitat	Reduce average channel velocities by 0.5-1 ft/s near Porter Creek during the 10-year peak flow

Increases in these key habitat metrics will address limiting factors in the reach to ESA listed spring Chinook salmon, as well as other salmonids (pink, sockeye, fall Chinook, and coho) (WRIA 1 2005) that use the reach. Many of the project goals are anticipated to be met by increasing the number of stable accumulations of large wood debris (LWD) through the use of engineered logjams (ELJs). In addition to these improvements, higher LWD loading would increase the number of pools, provide additional hydraulic complexity leading to sorting of spawning gravels, reducing channel energy through shear stress partitioning, greater in-stream cover, and locally increased water elevations to improve side channel and floodplain connectivity.

## Restoration Recommendations

Habitat conditions within the project reach are degraded in large part due to reach and watershed scale impacts to the Middle Fork watershed, including historic clearing of riparian forests, removal of in-stream wood, and a historic trend of increasing peak flows. A geomorphic assessment (NSD 2013) identified logging of the riparian corridor and removal of instream LWD as contributing to general incision and channel instability (higher channel migration rates and avulsion frequency) throughout the Middle Fork. Given the watershed and geomorphic conditions, this reach of the river is naturally susceptible to significant changes as variations in LWD loading, sediment supply and flows occur. The loss of functional and stable wood (trees greater than 4-ft in diameter and over 100-ft in length) and logjams could easily explain the historic trend in channel incision, channel instability, and lack of pools. The original forest had trees that would have obstructed the entire river channel when they fell that would easily have formed stable logjams that overtime would have created base level control and reduced the rate and magnitude of fluvial changes. With the loss of stable wood, the river has increased its streamflow energy and sediment transport capacity resulting in scour that has gradually lowered the channel and increased channel migration. When combined with shorter channel lengths resulting from on-going channel migration and avulsions, incision has been further exacerbated, creating a positive feedback loop. Numerous large stable wood placements in the form of ELJs are critical to reverse this feedback loop to slow incision and habitat degradation. Without countermeasures, incision and channel instability will continue, further simplifying and isolating habitat features. Disconnection of off-channel habitats (floodplains, floodplain side channels, and tributaries) has already been documented (NSD 2013), and would be anticipated to worsen with continued incision and channel migration. With evidence that peak flows may be increasing as a result of the warming climate (Mote 2006; Hamlet and Lettenmaier 2007; Abbe et al. 2008; Mote et al. 2008, Lee and Hamlet 2011; Neiman et al. 2011), it is even more important to aggressively reload the Middle Fork with stable wood and accelerate reforestation of riparian and floodplain areas. To ensure ELJ placements are engaged a high percentage of the time, placements should be made across the active channel width whenever possible. Observations of constructed LWD placements and persistent natural LWD accumulations within the Middle Fork suggest that stable LWD is very effective at creating flow obstructions leading to sediment deposition and channel migration away from the stable LWD locations. To combat this trend, ELJ placements that span the width of the active channel will ensure that as the low flow channel migrates across the active channel, it will be engaged with stable LWD at one or multiple locations.

The proposed restoration actions are primarily focused on increasing stable LWD in the form of ELJs within the project reach to meet the restoration objectives. Increasing stable LWD within the channel is anticipated to create geomorphic responses listed below, which in turn will address restoration goals.

GEOMORPHIC RESPONSES INDUCED BY LWD	RESTORATION GOALS THAT WILL BENEFIT
• Primary and secondary pool formation	3
• Sediment deposition downstream in the lee of LWD	2, 4, 5
• Increase water surface elevations	1, 2, 6
• Sediment grain size sorting	2
• Bed aggradation	1, 4, 6
• Spreading high flows into multiple channels	2, 4, 6
• Deflecting high flow energy away from existing critical habitat to improve stability	1, 2, 4, 7

The addition of stable LWD to the project reach will contribute to achieving all of the restoration goals, with habitat benefits that can be summarized as:

- Increasing channel roughness and partitioning shear stress (improving stability)
- More deep water cover refugia (pools),
- Increasing spawning gravel deposits (sediment deposition & sorting),
- Increased side channel habitat (increased water surface elevations, bed aggradation),
- Increased floodplain connection (increased water surface elevations, bed aggradation), and
- Improve stability of critical floodplain tributary habitat.

In addition to these habitat benefits from the geomorphic response, in-stream cover and edge habitat would both increase and benefit from stable LWD within the project reach. ELJs are designed to emulate the function of the large old growth snags once found throughout the river. Historically (pre-European settlement), one old growth snag would have been easily capable of obstructing the entire river channel within the project reach. Evidence of these trees was observed in the field, with numerous stumps 6-feet or more in diameter observed within the project area. Natural logjams and ELJs have been shown to be very effective in deflecting flow to create forested islands and side channels, raising river stage when they occlude much of the bankfull channel to backwater the river and aggrade the channel bed upstream (Abbe et al 2003, Montgomery and Abbe 2006).

## CONCEPTUAL AND PRELIMINARY DESIGN DEVELOPMENT

The conceptual restoration design for the Middle Fork were developed to meet the restoration objectives and informed by the geomorphic, hydraulic and hydrologic analyses completed (NSD, 2013). Conceptual restoration plans were submitted to NSEA in December 2013. Due to the size of the reach, distinctly different geomorphic segments to the river, and the number of proposed restoration elements, the project reach was divided into 6 distinct sub-reaches. The site sequence was chosen to start with the furthest upstream site (Sub-Reach 6) and work downstream to Sub-Reach 1 at the confluence with the North Fork Nooksack River. The sequencing was chosen to begin from the upstream direction (Sub-Reach 6) and progress downstream due to recent avulsions and channel migration processes within the Middle Fork. In order to ensure the success of each site, restoration actions are recommended to begin at the upstream end of each sub-reach to minimize the possibility of avulsion through the restored sites. Due to the size of Sub-Reach 6, and the number of proposed ELJs, the sub-reach was divided into 5 phases to facilitate funding the project over several years and the in-stream construction period on the Middle Fork.

During the previous conceptual design phase it was decided through communications with NSEA and LNR to proceed with preliminary design of the Phase 1 project reach, beginning just downstream of Mosquito Lake Road Bridge. ELJs located within this Phase 1 will have significant downstream effects on subsequent Phases by reducing streamflow energies and increasing channel stability in a sub-reach that has been highly dynamic within recent history. However, given the geomorphic conditions at the divide between the left and right channels, the channel should be expected to continue dynamic behavior in the future (varying percentage of flow down each channel flow path). ELJs will also provide bounds on future channel response (less likely for a full avulsion to one channel) through the formation of stable hard points. Additional ELJs placed in the left channel downstream of the flow divide at RM 4.85 will provide local habitat benefits, as well as partitioning shear stress upstream of the Bear Creek and Peat Bog Creek tributaries.

## Project Components

To achieve the restoration objectives, conceptual designs and layouts for ELJ placements were developed within the project area (see Appendix A). ELJ structure types were developed to mimic the size, form, and function of historic stable LWD within the Middle Fork, using observations from persistent LWD accumulations observed during field reconnaissance. These ELJs are constructed with a core of structural logs partially embedded into the channel and arranged to induce a desired hydraulic and geomorphic effect. Each ELJ includes a large volume of smaller (racking) logs packed on the upstream end and flanks of the ELJs to provide complex interstitial cover for fish and invertebrates, and additional stability to the structure by forcing scour away from the core structure. Existing natural logjams within the project reach were used to size the proposed structures, as well as emulate the ecological and geomorphic function currently contributing to beneficial habitat. Based on these criteria, 3 structure architectures are proposed, each unique in the geomorphic and habitat benefits provided. The developed structure types are as follows:

- TYPE-1 ELJ – Type-1 ELJs are the largest proposed structures with a width and length of 85- and 55-feet, respectively. Type-1 ELJs will mimic the geomorphic, ecologic and hydraulic function once provided by large old growth trees that once lined the banks and were recruited into the channel of the Middle Fork. These structures are intended to force primary pool formation on the upstream end, promote stable forested island formation downstream, increase in-stream cover, sort spawning sized gravels, and with a sufficient number of structures densely spaced, will decrease basal shear stresses reach-wide to promote bed aggradation. Type-1 ELJs will be excavated into the channel bed to protect the structure from scour and will be post supported. Due to the construction cost of this ELJ type, placements were limited to high energy or severe hydraulic locations where a simpler, less robust ELJ would be less stable.
- TYPE-2 ELJ – Type-2 ELJs are a medium sized structure with a width and length of 60- and 50-feet, respectively. Type-2 ELJs will provide similar geomorphic, ecologic and hydraulic benefits as the Type-1 structures at a smaller scale, and are strategically placed to function with adjacent ELJs to increase habitat benefits while providing cost savings. Type-2 structures will be excavated into the channel bed to protect the structure from scour; are post supported, and cost less than Type-1 structures.
- TYPE-3 ELJ – Type-3 ELJs are a large structure with a width and length of 75- and 50-feet, respectively. Type-3 ELJs will provide similar geomorphic, ecologic and hydraulic benefits as the Type-1 structures at a much lower cost. The Type-3 ELJ design was partially developed to mimic the vertical members (in the form of mature second growth trees) observed in the persistent LWD accumulation at RM 4.5 in the right channel, and also on a pile array ELJ

developed for the Upper Quinault River (see Figure 2). To reduce construction costs, Type-3 structures will be excavated a nominal depth into the channel, are post supported, and uses a smaller number of key pieces. To have its intended effect, the Type-3 structure relies on trapping mobile wood moving through the project reach to create a large stable wood accumulation over time. Minimizing the excavation depth and number of key pieces results in significant cost savings, but also a less robust structure in the short-term. Stability will increase over time as additional logs rack onto the structure. Type-3 structures are located in sub-reaches that are lower energy or have less severe hydraulic conditions where natural LWD would be likely to deposit and where the structure is at a lower risk of becoming unstable. Similar low cost structures have been developed and successfully implemented on the Upper Quinault River as shown in Figure 2 and offer a great opportunity to re-introduce stable LWD on a reach scale in the Middle Fork.

## Stakeholder Consultation

Following internal discussions with the project team, the conceptual designs for the project reach were presented to WRIA1 Salmon Staff Team on December 6, 2013. Entities present at the meeting include NSEA, the Nooksack Tribe, the Lummi Tribe, Whatcom County, and Washington Department of Fish and Wildlife (WDFW). During the presentation geomorphic and hydraulic findings, restoration recommendations were discussed and input solicited. Feedback received from all entities was positive and comments received on the conceptual designs were incorporated into the preliminary design drawings completed in 2013. . Following the preliminary design process, additional funding was acquired by LNRD and the final design process for Phase 1 and 4 was initiated in the spring of 2015. During the final design process, consultation with Washington Department of Natural Resources (WA DNR), WDFW, Corps of Engineers, and local stakeholders was completed during both in office and field visits. Comments from these consultations were incorporated into the final design drawings (Appendix A).

## FINAL DESIGN DEVELOPMENT

Following the conceptual design, preliminary design for Phase 1, and input from project stakeholders, final designs plans for Phase 1 and 4 (Appendix A) were developed to achieve the restoration objectives, and expand upon restoration recommendations. The final design for Phase 1 and 4 refined ELJ locations based on initial hydraulic results and field-observed channel changes since the preliminary design effort was completed. The Middle Fork Nooksack experienced the flood of record in November 2015, causing significant channel changes to the Phase 1 project area including 30 ft of lateral channel migration towards the right and loss of numerous NSEA structures (NSD, 2016). Modifications were made to the structure locations to account for channel changes, and ELJ designs were evaluated to better resist expected scour in the project and reduce excessive accumulation of mobile wood. The TESC plan was also revised based on adjustments to the current low-flow channel in the Phase 1 project area. The following section provides additional descriptions for each site and structure and evaluates each proposed structure in relation to the restoration objectives.

### Phase 1 Project Area

The restoration approach for the Phase 1 project is to improve channel stability, an anabranching planform, and habitat quality and quantity through the creation of stable accumulations of LWD. These accumulations will be established by constructing ELJs that will distribute flows in the channel,



forming stable forested islands downstream of the ELJ over time. The resultant anabranching planform will reduce channel widths and increase depths compared to the current channel, and the ELJs will maintain pools as downward vortices are created as flow impinges on the structures.

Specific objectives within the Phase 1 project area are to:

1. Dissipate high streamflow energies through adding roughness, disrupting flow patterns, and partitioning shear stress, leading to increased channel stability over time,
2. Promote the formation and growth of forested islands in the lee of proposed ELJs,
3. Create stable pool habitat with cover immediately upstream and/or adjacent to proposed ELJs,
4. Increase the frequency of stable spawning habitat by partitioning shear stress in the channel to reduce average grain size to more suitable spawning sized gravels, as well as development of depositional gravel pockets in the lee of proposed ELJs,
5. Trap mobile LWD to further obstruct flow and provide additional habitat benefits, and maximize residence time of large trees within the project reach susceptible to recruitment as the channel adjusts to ELJs,
6. Increase floodplain and side channel connectivity throughout the project reach by increasing flow depths over a range of discharges.

The proposed ELJs are laid out in strategic locations to maximize their hydraulic, geomorphic, and habitat forming benefits both immediately following construction and in the long term. The ELJs will have local influences from individual structures, and will work together to illicit reach scale influence to meet the project goals. Individually, the proposed ELJs will provide pool and cover habitat, locally increase water surface elevations when engaged with flow, trap mobile LWD during floods, and increase instream roughness. However, when they are considered together their function impacts a much larger area, and can begin to restore broader goals of floodplain and side channel connectivity, improved channel stability through shear stress partitioning, and maintaining stable habitat features over time. It is anticipated that through reduced velocities due to ELJ placement, aggradation will occur in the left channel flow path which will increase flow entering the right flow path at a range of flows. The anticipated influence of each structure will vary slightly depending on the configuration of the main stem channel. Given the dynamic nature of the Middle Fork, it is anticipated that the channel location will change over time, varying the degree to which individual structures are engaged with flow and thus their influence on hydraulics and geomorphic response. Specific descriptions for each structure placement relative to the current channel alignment within this site are as follows;

- ELJ 1-2-1 is a Type 2 structure that is designed to create a secondary pool on the right side of the main stream channel, encourage flow into the existing side channel along the right bank at RM 4.9 and help reduce further erosion and migration of the main stem into the right bank and towards Mosquito Lake Road upstream of the channel split.
- ELJ 1-2-2 is a Type 2 structure designed to create and maintain a primary pool in the main stem channel, deflect flow toward the inlet of the right channel flow path and ELJ 1-3-10, and promote stable vegetated island formation by protecting the developing riparian forest in its lee. Local increase in water surface elevation will further contribute to flow entering the right channel flow path during high flows.
- ELJ 1-2-3 is a Type 3 structure designed to create a secondary pool in the main stem (left) channel, deflect flows toward the right bank and into ELJ 1-1-4, limiting channel migration to the left that would further widen the channel.

- ELJ 1-1-4 is a Type 1 structure that is designed to create a primary pool in the main stem (left) channel, deflect flows to either side of the structure (toward ELJ 1-3-5 and ELJ 1-2-6), and promote stable vegetated island formation. This structure will also help to trap trees recruited into the channel from anticipated channel adjustments due to flow deflection at the upstream ELJs 1-2-2 and 1-2-3.
- ELJ 1-3-5 is a Type 3 structure that is designed to create a secondary pool in the main stem (left) channel, deflect flows to the right of the structure, limiting channel migration to the left that would further widen the channel, and contribute to reach scale increases in flow depth (in combination with ELJ 1-2-6 and 1-3-7) to improve floodplain connectivity and decrease shear stress to promote bed fining and channel stability. This structure will also help to trap trees recruited into the channel from anticipated channel adjustments due to flow deflection at upstream ELJs.
- ELJ 1-2-6 is a Type 2 structure that is designed to create a primary pool in the main stem (left) channel, deflect flows to either side of the structure (toward ELJ 1-3-7 and ELJ 1-3-8), and contribute to reach scale increases in flow depth (in combination with ELJ 1-3-5 and 1-3-7) to improve floodplain connectivity and decrease shear stress to promote bed fining and channel stability. This structure will also help to trap mobile wood from flow deflection at upstream ELJs.
- ELJ 1-3-7 is a Type 3 structure that is designed to create a secondary pool in the main stem (left) channel, deflect flows to either side of the structure (toward ELJ 1-3-8), and contribute to reach scale increases in flow depth (in combination with ELJ 1-3-5 and 1-2-6) to improve floodplain connectivity and decrease shear stress to promote bed fining and channel stability. This structure will also help to trap trees recruited into the channel from anticipated channel adjustments due to flow deflection at upstream ELJs.
- ELJ 1-3-8 is a Type 3 structure that is designed to create a secondary pool in the main stem (left) channel, deflect flows to either side of the structure, and promote stable vegetated island formation. This structure would be engaged with flows greater than base flow under the current condition, and would provide a stable hard point should the channel migrate toward the structure. This structure will also help to trap mobile wood from flow deflection at upstream ELJs 1-3-5, 1-2-6 and 1-3-7.
- ELJ 1-1-9 is a Type 1 structure that is located on the left bank of the main stem (left) channel and is designed to create a secondary pool, deflect flows to the right of the structure, limiting channel migration to the left that would further widen the channel. This structure will also help to mobile wood from flow deflection at all upstream ELJs.
- ELJ 1-3-10 is a Type 3 structure that is designed to create a secondary pool in the high flow (right) channel, deflect flows to either side of the structure (toward ELJ 1-3-11), and promote stable vegetated island formation that will narrow the high flow corridor over time.
- ELJ 1-3-11 is a Type 3 structure that is designed to create a secondary pool in the high flow (right) channel, and deflect flows to either side of the structure, and promote stable vegetated island formation that will narrow the high flow corridor over time.

**Table 1 – Phase 1 Restoration Element Summary.**

RESTORATION ELEMENT	TYPE	PRIMARY RESTORATION GOALS ACHIEVED*
ELJ 1-2-1	2	1, 2, 4, 5, 6
ELJ 1-2-2	2	1, 2, 3, 5, 6
ELJ 1-2-3	2	1, 4, 5, 6
ELJ 1-1-4	1	1, 2, 3, 4, 5, 6
ELJ 1-3-5	3	1, 4, 5, 6
ELJ 1-2-6	2	1, 2, 3, 4, 5, 6
ELJ 1-3-7	3	1, 2, 4, 5, 6
ELJ 1-3-8	3	1, 2, 5, 6
ELJ 1-1-9	1	1, 4, 5, 6
ELJ 1-3-10	3	1, 2, 5, 7
ELJ 1-3-11	3	1, 2, 5, 7

\* numbers correspond to list of restoration goals on pages 1 and 3

## Phase 4 Project Area

The restoration approach for the Phase 4 project is to improve channel stability, encourage an anabranching planform, and habitat quality and quantity through the creation of stable accumulations of LWD. Implementation of Phase 4 is also opportunistic, as construction costs and impacts in this area will be significantly less while the main stem channel is within the left split at the divide (RM 4.85). Phase 4 will reduce long-term erosion risk to Mosquito Lake Road should main stem flow avulse or switch back to the right channel sometime in the future. Stable accumulations of LWD will be established by constructing ELJs that will distribute flows in the channel, forming stable forested islands downstream of the ELJ over time. The anabranching planform will reduce channel widths and increase depths compared to the current channel, and the ELJs will maintain pools as downward vortices are created as flow impinges on the structures.

Specific objectives within the Phase 4 project area are to:

1. Promote the formation and growth of forested islands in the lee of proposed ELJs,
2. Create stable pool habitat with cover immediately upstream and/or adjacent to proposed ELJs,
3. Increase the frequency of stable spawning habitat by partitioning shear stress in the channel to reduce average grain size to more suitable spawning sized gravels, as well as development of depositional gravel pockets in the lee of proposed ELJs,
4. Trap mobile LWD to further obstruct flow and provide additional habitat benefits, and maximize residence time of large trees within the project reach susceptible to recruitment as the channel adjusts to ELJs,
5. Protect floodplain tributary habitat associated with Porter Creek,
6. Reduce erosion risk along the toe of the eroding right bank at the counterclockwise bend along Mosquito Lake Road.



The proposed ELJs are laid out in strategic locations to maximize their hydraulic, geomorphic, and habitat forming benefits both immediately following construction and in the long term. The ELJs will have local influences from individual structures, and will work together to illicit reach scale influence to meet the project goals. Individually, the proposed ELJs will provide pool and cover habitat during high flows, locally increase water surface elevations when engaged with flow, trap mobile LWD during floods, increase instream roughness, and reduce velocities and shear when placed along banks. However, when they are considered together their function impacts a much larger area, and can begin to restore broader goals of floodplain and side channel connectivity, improved channel stability through shear stress partitioning, and maintaining stable habitat features over time. The anticipated influence of each structure will vary slightly depending on the configuration of the main stem channel. Given the dynamic nature of the Middle Fork, it is anticipated that the channel location will change over time, varying the degree to which individual structures are engaged with flow and thus their influence on hydraulics and geomorphic response. Specific descriptions for each structure placement relative to the current channel alignment within this site are as follows;

- ELJ 4-3-27 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure (toward ELJ 4-2-28), contribute to reach scale increases in flow depth (in combination with ELJ 4-2-28) to improve floodplain connectivity and decrease shear stress to promote bed fining, channel stability, and stable vegetated island formation.
- ELJ 4-2-28 is a Type 2 structure designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure, contribute to reach scale increases in flow depth (in combination with ELJ 4-2-27) to improve floodplain connectivity and decrease shear stress to promote bed fining, channel stability, and stable vegetated island formation.
- ELJ 4-2-29 is a Type 2 structure designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure (toward ELJ 4-3-30), contribute to reach scale increases in flow depth (in combination with ELJ 4-3-30) to improve floodplain connectivity and decrease shear stress to promote fining, channel stability, and stable vegetated island formation.
- ELJ 4-3-30 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure, contribute to reach scale increases in flow depth (in combination with ELJ 4-2-29) to improve floodplain connectivity and decrease shear stress to promote bed fining, channel stability, and stable vegetated island formation.
- ELJ 4-3-31 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure (toward ELJ 4-3-32), and promote stable vegetated island formation.
- ELJ 4-3-32 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure, and promote stable vegetated island formation. This structure in combination with ELJ 4-3-33 will work to deflect flows into a prominent natural logjam and side channel within the left floodplain. . This structure will also help to trap mobile wood recruited from flow deflection at all upstream sources and ELJs.
- ELJ 4-3-33 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure, promote stable vegetated island formation, and increase flow depth in the

side channel between ELJs 4-3-32 and 4-3-33 where a naturally occurring logjam has formed. This structure in combination with ELJ 4-3-32 will work to deflect flows into a prominent natural logjam and side channel within the left floodplain. This structure will also help to trap mobile wood recruited from flow deflection at all upstream sources and ELJs.

- ELJ 4-2-34 is a Type 2 structure that is designed to create a secondary pool at high flows and in future conditions in the main stem (right) channel and deflect flows to the left of the structure, reducing velocities and shear stress along the toe of the right bank. This structure will also help to trap mobile wood recruited from flow deflection at all upstream sources and ELJs.
- ELJ 4-2-35 is a Type 2 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel and deflect flows to the left of the structure and backup water upstream, reducing velocities and shear stress along the toe of the right bank. This structure will also help to trap mobile wood recruited from flow deflection at all upstream sources and ELJs.
- ELJ 4-2-36 is a Type 2 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel and deflect flows to the left of the structure (toward ELJ 4-3-37), reducing velocities and shear stress along the toe of the right bank. This flow deflection to the left will limit the channels ability to migrate into the right bank floodplain where Porter Creeks enters the Middle Fork. .This structure will also help to trap mobile wood recruited from flow deflection at all upstream sources and ELJs
- ELJ 4-3-37 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the main stem (right) channel, deflect flows to either side of the structure (toward ELJ 4-3-38), and promote stable vegetated island formation This structure will also help to trap mobile wood recruited from flow deflection at all upstream sources and ELJs.
- ELJ 4-3-38 is a Type 3 structure that is designed to create a secondary pool at high flows and in future conditions in the secondary main stem (right) channel, deflect flows to either side of the structure, promote stable vegetated island formation, and reduce velocities in the lee of the structure at the mouth of Porter Creek. This structure will also help to trap mobile wood from flow deflection at all upstream sources and ELJs.

Table 2 – Phase 4 Restoration Element Summary.

RESTORATION ELEMENT	TYPE	PRIMARY RESTORATION GOALS ACHIEVED*
ELJ 4-3-27	3	1, 2, 3, 4
ELJ 4-2-28	2	1, 2, 3, 4
ELJ 4-2-29	2	1, 2, 3, 4
ELJ 4-3-30	3	1, 2, 3, 4
ELJ 4-3-31	3	1, 2, 3, 4
ELJ 4-3-32	3	1, 2, 3, 4
ELJ 4-3-33	3	1, 2, 3, 4
ELJ 4-2-34	2	1, 3, 6
ELJ 4-2-35	2	1, 3, 6
ELJ 4-2-36	2	1, 3, 6
ELJ 4-3-37	3	1, 2, 3, 4, 5
ELJ 4-3-38	3	1, 2, 3, 4, 5

\* numbers correspond to list of restoration goals on pages 1 and 3

## Site Access

Several site access routes were identified that will be potentially be utilized to construct the proposed restoration elements. Temporary bridge crossings from the Mosquito Lake Road Bridge parking area will be required at the site to reach the forested islands to construct Phase 1 ELJs. Up to 4 temporary bridge locations are proposed, however, depending on the location of the low flow channel during construction, the number and locations of proposed temporary bridge locations may vary. Access routes follow exposed unvegetated gravel bars where possible to minimize impacts to adjacent riparian vegetation and to avoid known existing LWD locations. The location of access routes will be verified prior to construction and modified to accommodate future channel migration and/or redistribution of LWD on bars. Phase 4 site access will utilize a decommissioned road running along the south side of Porter Creek from Mosquito Lake Road. It is expected only minor improvements will be necessary to utilize this access route. No temporary bridges will be required due to all of the Phase 4 project area being dry during the summer low-flow construction window.

## Spawning Impacts

Spawning redd locations for endangered salmonids were considered in the placement of proposed restoration elements. Spawning redd data from 2000 to 2010 for the project area was provided by LNRD and NSEA in GIS format, with more recent redd locations (2012 and 2013) provided in graphic form. Redd locations were overlaid with proposed ELJ, access road, and temporary bridge locations to ensure these elements did not interfere with recently observed redd locations. All structures to be constructed in the wetted channel will be reviewed by a permitting agency and LNR biologist prior to construction starting. If any redd or significant fish activity is observed in the immediate

structure location, that structure will either not be constructed or relocated at the direction of the NSD engineer of record.

To further reduce impacts to the endangered salmonids, proposed ELJs will be constructed during the allowable in-stream construction window and temporary erosion control measures will be implemented in accordance with Department of Ecology Stormwater Management Regulations and Best Management Practices for Western Washington. Based upon the distance to observed redd locations, construction period, construction methods, and results from the hydraulic model, the proposed ELJ locations are not anticipated to adversely affect known spawning locations. Furthermore, the location of proposed ELJs proximal to observed redd locations are anticipated to create scour holes and adult holding habitat for spawning salmonids that will enhance these locations over time.

## Proposed Condition Hydraulics

Updated hydraulic models for the Phase 1 and 4 project reaches were developed as part of the geomorphic assessments (NSD 2013, NSD 2016). Topography for the model mesh was based on 2013 LiDAR data acquired from the Puget Sound LiDAR Consortium to represent channel and floodplain topography. It is important to note, the channel conditions have changed significantly since the 2013 LiDAR data was acquired reducing the precision and adding uncertainty to the modeling efforts. The horizontal and vertical datum of all data utilized and referenced in the report is Washington State Plane Coordinates North Zone NAD83 feet and NAVD 88-feet, respectively. Review of 2013 LiDAR indicates the streamflow of the Middle Fork at the time of the LiDAR acquisition (March 31, 2013) was 510-cfs. Due to the limited light penetrating abilities of LiDAR equipment, channel topography utilizing only LiDAR is representative of the water surface at the time of LiDAR acquisition, not the channel bottom. Review of the 2013 LiDAR data indicates the channel bottom topography is not well represented but the majority of out of water areas (gravel bars and floodplain) is representative of current conditions. Modifications were made to the LiDAR topography to represent existing wood accumulations and engineered logjams based on field observations in November and December 2015. Manning's roughness values were applied based on these field observations and recent aerial photographs to represent changes since the earlier model runs were performed.

The proposed conditions mesh was created by adjusting the topography to represent the proposed ELJ structures and modifying the roughness values in these areas to reflect the added wood. ELJ locations in the proposed conditions model run were adjusted based upon LNR comments and field observations made by NSD and LNR in the spring of 2015, since the earlier model runs were performed. The placement of ELJ 1-2-2 in the model was adjusted in the model to reflect the geomorphic significance/location of the structure in relation to the 2013 LiDAR topography. The structure was shifted upstream to be at the location of the RM 4.85 flow split at the time of LiDAR acquisition in 2013. Fall 2015 floods caused the river to migrate 30 ft to the north and the actual field placement of ELJ 1-2-2 will be based on the current flow split location (NSD 2016).

The 1-year, 10-year and 100-year flows were modeled using the existing conditions and proposed conditions meshes. Steady-state flow (discharge does not vary with time) inputs of 1,890 cfs, 14,390 cfs, and 25,490 cfs were used for the 1-, 10-, and 100-yr models, respectively. These flows were calculated by subtracting the flow during the LiDAR flight of 510 cfs from the peak flows calculated for the site using 2015 data. The model runs also assumed a non-deformable bed (no adjustments for scour, sediment transport, erosion, and deposition).

The results of the proposed conditions hydraulic modeling demonstrate how the design achieves the project goals by altering the hydraulic conditions during the 1-, 10-, and 100-year flood. The proposed condition modelling results do not show a significant increase in flow in the right flow path (Figure 3) with the distribution of modeled flow in the right and left flow splits shown in Table 3. The amount of change reflected in the modeling results is generally within the normal variance of model results and not considered significant. These results are contrary to hydraulic modeling results performed during the preliminary design process and are primarily attributed to inaccuracies in the 2013 LiDAR topography and it's relation to planned Phase 1 and 4 ELJs. The results can also be attributed to a primary modeling assumption of using non-deformable bed conditions which do not account for aggradation/degradation that is expected due to decreases in flow velocity, decreases in shear stress, and shear stress partitioning in the left flow path. These factors will result in decreased sediment transport capacity, leading to long term aggradation and fining of the channel bed to more suitable spawning sized gravels (Figure 5). It is anticipated that aggradation and sediment deposition in the left flow path will encourage a more even flow split in future conditions. The likelihood of these effects occurring will be dependent on the occurrence of future high flow and sediment events within the Middle Fork Nooksack watershed. Increased flow in the right channel flow path will result in a dramatic increase in channel length and edge habitat available. Figure 4 is useful in predicting anticipated channel response to the proposed ELJs, where areas of increased velocity likely indicating an increased chance of channel migration, and areas of decreased velocity predictive of areas that will aggrade.

**Table 3 – Summary of Flow Distribution at RM 4.85.**

Flow	Channel	Left Channel	Right Channel
Q1	Existing Conditions Q (cfs)*	2264 cfs (98.5%)	34 cfs (1.5%)
	Proposed Conditions Q (cfs)*	2265 cfs (98.5%)	35 cfs (1.5%)
	<b>Change in Q (% of total Q)</b>	<b>0%</b>	<b>0%</b>
Q10	Existing Conditions Q (cfs)*	9548 cfs (65%)	5223 cfs (35%)
	Proposed Conditions Q (cfs)*	9532 cfs (64%)	5317 cfs (36%)
	<b>Change in Q (% of total Q)</b>	<b>-1%</b>	<b>+1%</b>
Q100	Existing Conditions Q (cfs)*	14879 cfs (60%)	10102 cfs (40%)
	Proposed Conditions Q (cfs)*	14932 cfs (59%)	10452 cfs (41%)
	<b>Change in Q (% of total Q)</b>	<b>-1%</b>	<b>+1%</b>

\*510 cfs was added to the calculated flows in the left channel to represent the flow at the time of the LiDAR flight

Engagement of structures during the 1-year flow event is important to create and maintain stable pool habitat, and to trap mobile wood moving through the reach, other important goals of the project. Eight of the eleven proposed ELJs in the Phase 1 project area are engaged with the 1-year flow extent (Figure 3), and are anticipated to create and maintain stable pool habitat with complex cover, and help increase residence time of mobile wood within the reach by trapping debris. In the Phase 4 project area, 2 of the 12 proposed structures are engaged during the 1-year flow (Figure 3). All Phase 4 structures are engaged at the 10-year flow (Figure 6).

For the 10-year flood event, average flow depths across the project reach are increased about 0.5-ft, with local increases greater than 2-ft (Figure 6) (NSD 2016). These increases in flow depth demonstrate greater floodplain and side channel connectivity within the project reach, another important goal of the project. These increases in depth are accompanied by decreases in channel velocities (Figure 7) averaging 1- ft/s along the channel within the project reach, and greater than 3 ft/s in some locations (NSD 2016). Most of the area shown as having increased velocity is floodplain inundated area that has low velocities under both the existing and proposed condition. These

results are consistent with that shown for the 1-year flood event, demonstrating that the habitat benefits realized by the project occur over a wide range of flow conditions.

## Scour Analysis

A scour analysis was performed to ensure the ELJ structures are designed and constructed to withstand the scour that may occur during severe flood events. For each ELJ type, only the ELJ experiencing the most severe hydraulic conditions (highest velocity and flow depth) was evaluated. The scour analysis was performed using empirical equations developed to predict scour and results from the 10-year proposed condition hydraulic analysis. The scour potential for all ELJs was evaluated following the procedures outlined in FHWA HEC-18, Fifth Edition (Arneson et al., 2012), FHWA HEC-20, Third Edition (Lagasse et al., 2001), and Scientific Investigation Report 2004-5111 (Chase and Holnbeck, 2004). Scour estimates were performed for the 10-year discharge and considered long-term degradation, contraction scour, and pier scour components. Scour related to long-term degradation and contraction scour was determined to be negligible for this project. Pier scour for this project was determined using the Simplified Chinese Equation developed by Landers and Mueller, 1996. The results of the scour analysis for each structure type are shown in Table 4, below. Key assumptions utilized during the scour analysis include;

- All flow was assumed perpendicular to structure face
- Approach depth was assumed to be the maximum structure face height at the time of construction
- Approach velocity was assumed to be the average thalweg velocity at the structure

**Table 4 – Summary of Scour Analysis for 10-Yr Peak Design Event.**

STRUCTURE TYPE	MAXIMUM POTENTIAL SCOUR* (FT)	DESIGN SCOUR DEPTH (FT)**
TYPE 1 (ELJ 1-1-9)	15.1	22.0
TYPE 2 (ELJ 1-2-2)	13.6	22.0
TYPE 3 (ELJ 4-3-27)	15.2	18.0

\* Scour depths presented are for the worst case for each structure type

\*\* Design scour depth is representative of embedment depth of vertical posts below the channel bed

To withstand the estimated scour, the bottom elevations of proposed ELJs will be placed below the estimated scour elevation and coarse channel material will be placed in front of each structure to inhibit scour that could destabilize the ELJ. The project will directly address general scour by reducing the river's sediment transport capacity and the predicted bed aggradation induced by the project will reduce the risks associated with scour. This scour assessment conservatively assumes that no racking logs are present on the upstream face of the ELJ, and that scour would initiate directly upstream of the ELJ face. All of the proposed ELJ types will be constructed with racking logs installed on the upstream face (minimum 10-ft thick) that will force scour initiation away from the ELJ core. Based on performance of recently constructed ELJs within the Nooksack watershed mobile LWD within the project reach is expected to rack onto proposed ELJ, further pushing scour away from the ELJ core.



## Stability Analysis

A stability analysis was performed to ensure the ELJ structures are designed and constructed to withstand the hydraulic forces that occur during severe flood events. For each ELJ type, only the ELJ experiencing the most severe hydraulic conditions (highest velocity and flow depth) was evaluated. The stability analysis was performed using force balance equations developed to predict buoyant and lateral (sliding) forces, results from the 10-year proposed condition hydraulic analysis, and material properties for the specific ELJ components. The stability for all ELJs evaluated followed the procedures outlined in D'Oust and Millar (2000), Abbe (2000), Shields et al. (2000), Brauderick and Grant (2000), and the Bureau of Reclamation Risk Based Design Guidelines (Knutsen and Fealko, 2014). Stability estimates were performed for the 10-year recurrence discharge and considered destabilizing forces related to the buoyancy of large wood and sliding force caused by the streamflow velocities and the stabilizing forces related to alluvium ballast, and the friction between the bottom of the ELJ and the channel. The results of the stability analysis in terms of the factor of safety (resisting forces/destabilizing forces) for each structure type are shown in Table 5, below. Key assumptions utilized during the stability analysis include;

- Thawleg hydraulic conditions (depth and velocity) adjacent to the structure are assumed to act on the structure face
- 50% of structure backfill remains
- Height of blocked obstruction is full height of wood and does not account for burial into channel bars or bed
- Forces are equally distributed amongst all piles
- Scour does not propagate completely through structure. 80% scour depth at front piles and outermost rear piles, 60% scour depth at interior piles, and 10% scour depth at inner rear piles
- Scour depth is averaged for all piles to calculate pile stability

**Table 5 – Summary of Stability Analysis for 10-YR Peak Design Event.**

STRUCTURE TYPE	BOUYANCY FS*	SLIDING FS*	LATERAL PILE BREAKAGE FS*
TYPE 1 (ELJ 1-1-9)	6.8	7.1	2.0
TYPE 2 (ELJ 1-2-2)	7.0	4.9	1.3
TYPE 3 (ELJ 4-3-27)	3.6	3.0	1.6

\* FS presented are for the worst case for each structure type

Type 1, 2, and 3 structures were designed to withstand buoyant and lateral forces using excavated timber posts and alluvium backfill. Estimates are considered conservative since channel aggradation will result in a reduction of drag forces (by decreasing area of wood exposed to flow), an addition of surcharge (log burial), a reduction in basal shear stress (by reducing hydraulic gradients and flow depths), and a reduction in effective shear stress acting on wood by the cumulative effect of the ELJs in partitioning basal shear stress. Additionally, stability was evaluated using the thalweg hydraulic conditions (depth and velocity) which are more severe than the forces acting on the face of the structure.

## Construction Cost Estimates

The construction cost estimate presented for this project (Appendix B) is largely based on our professional judgment, consultation with construction contractors and recent experience with similar projects. Cost data for large wood was provided by Lummi Natural Resources Department from recent project experience within the watershed. Quantity estimates are considered approximate but are sufficiently accurate for the preliminary design phase.

Construction costs were calculated in a single Microsoft Excel workbook, using consistent unit costs for each construction element or quantity. Construction quantities for each element were multiplied by their respective unit costs, and the resulting products totaled into a construction sub-total. Additional fees for taxes, contingencies, and incidentals were accounted for as a percentage of the construction sub-total. The construction sub-total was then increased by the percentages of the additional fees to estimate the total construction cost. The construction costs do not include engineering and permitting fees.

## RISK ASSESSMENT

The proposed restoration design is intended to improve channel stability and habitat quantity and quality throughout the project reach. The introduction of ELJs will also result in changes to water surface elevations that meet the goal of improving side channel and floodplain connectivity, but this change must be balanced so as not to put existing habitat, forest, and local infrastructure at risk. Thus it is critical to evaluate the hydraulic effect of the proposed ELJs to ensure they have no undesired impacts. A risk assessment was conducted to evaluate potential impacts of the proposed restoration actions and to document that no adverse effects to habitat relative to the existing condition are predicted

Risk is a function of the probability of a hazard occurring (such as structure failure/washout, flood inundation, or boater entanglement) and the consequences of that event (e.g., habitat loss, property damage, or injury). If an event has little or no consequence then the associated risk would be relatively low, whereas a high negative consequence coupled with a high probability of occurrence results in a high risk factor. Rivers and natural systems have evolved to function within a wide range of conditions, however these processes are not always consistent with human needs and expectations. The Middle Fork is a dynamic river in its current condition and high flows pose risks to nearby infrastructure, developing riparian forest, and recreational users. The primary natural hazards for the project area are related to flood and erosion risks, including lateral bank erosion (channel migration/avulsion), sediment delivery from mass wasting events upstream, riparian woody debris recruitment, and in-stream LWD. Non-natural hazards include failure of in-stream structures, creation of boating hazards, changes in inundation/channel forming processes, the establishment of non-native vegetation, and construction impacts. Longer-term hazards such as climate change were not addressed as part of this assessment. This risk assessment establishes due diligence in evaluating the proposed design for the Phase 1 and Phase 4 Middle Fork restoration and consists of the following elements:

- Assessment of short-term risk associated with construction activities
- Assessment of potential impacts to habitat and infrastructure
- Description of how ELJs will influence channel migration
- Assessment of potential impacts of ELJs for recreational users of the river

- Description of risks of a no-action alternative

## Short-Term Risks from Construction Activities

Several hazards have been identified related to construction activities that pose potential risks to construction delays, water quality, and habitat during construction. Construction activities included in this risk assessment are:

- Earthmoving
- Re-vegetation
- Water management
- In-stream structures

### Earthmoving

Primary earthmoving activities included in the design are excavation of ELJ placements and scour pits as well as backfill of excavated material into ELJs. Grading associated with staging and stockpile areas, and establishment of proposed access routes is anticipated to be minimal. Any areas that are excavated or filled during construction will clear, and will remain exposed in the short-term as vegetation re-establishes naturally or as a result of planting. The proposed design plans incorporating re-vegetation in some areas, the risk associated with earthmoving is very low.

The risk associated with flooding inundation and erosion is very low for the project area during construction given anticipated low-flows during the proposed construction time frame. Construction areas that are within the wetted channel during construction will be isolated using temporary cofferdams where applicable to minimize inundation risk. All materials and equipment will be stored above/outside of the ordinary high water line to minimize risk from unlikely high flows during construction.

### Re-Vegetation

Following construction the backfilled ELJs and any disturbed areas above the ordinary high water line (access routes, staging areas where applicable) will be planted and/or seeded to initiate establishment of native vegetation. Habitats to be formed include coniferous forest and riparian deciduous forest. The primary risk to establishment of the plantings is from flood erosion in the growth period following construction and available root water following installation. Selection of appropriate native vegetation and installation to sufficient depths will be used to mitigate any risk to the success of re-vegetation efforts.

### Water Management

Some of the proposed ELJ locations will infringe on the low flow channel during construction, requiring water management techniques to isolate the work area and divert water elsewhere. Prior to the initiation of isolation and construction of each structure, the wetted channel bed will be inspected for recent fish usage, include redds. Should a recent redd be present within the area proposed to be isolated, the proposed ELJ location will be changed to avoid impacts to fish usage. If no fish usage is documented, the area will be isolated using bulk bags or other agency approved method. Water will be pumped from the isolated area and diverted from the work area prior to starting excavation for the proposed ELJ. Water diverted from the isolated work area will be diverted onto the adjacent floodplains in a location such that it infiltrates into the ground completely

prior to re-entering the river. If diverted water remains as turbid surface flow as it re-enters the river, BMPs will be employed to slow the flow, filter suspended sediment, and/or otherwise keep turbidity in the river below the threshold set by permit applications. Periodic sampling for turbidity in the river downstream of the isolated work area and re-entry point of diverted waters will be conducted to ensure turbidity is maintained within levels permitted. Should turbidity remain above threshold levels, work will stop until BMPs are employed to manage turbidity below allowable levels. In the vicinity of ELJs 1-2-3 and 1-3-5, flow is expected at the time of construction. Using bulk bags to isolate the structure excavation would completely block flow along the left bank channel thread. To avoid fish stranding and dewatering of the left bank channel thread, a temporary diversion channel is to be excavated through the channel bar and filled with native material at the completion of construction of the adjacent ELJ. Turbidity is expected with the initial flow of the water through the temporary diversion channel, but turbidity is not anticipated to be above threshold levels set by the permit applications.

### In-Stream Structures

The project design includes in-stream ELJs (Appendix A). Construction of these design elements will be performed when low-flow conditions exist. The primary risk to project elements during construction is from flooding of the work area. Due to the hydrologic regime and work occurring during low-flow conditions, the risk from flooding is very low. Should inundation of the work area occur during construction, construction would be halted immediately until the water subsides.

## Potential Impacts to Habitat and Infrastructure

Improving habitat quality and quantity throughout the project reach is the main goal of the proposed restoration design. By activating additional side channels and reconnecting the floodplain, habitat will be created through the engagement of habitat features more frequently by increasing water elevations and local deflection into side channel inlets. Engaging these areas is regarded as an improvement relative to existing habitat conditions, but it may also result in decreased flow depths and velocities in the current channel that could negatively impact existing habitat. However, these anticipated reductions in mainstem flow will benefit the project goals of countering channel incision and reducing avulsion potential by partitioning shear stress in the project reach, resulting in bed aggradation in the current (left) main channel, reach scale elevated water surface elevations, and thus enhanced floodplain and side channel connectivity. Distributing flows between the left and right flow paths in the project reach will also add over a mile of active channel, more than doubling the amount of edge habitat contributing to in-stream cover and complexity (Figure 3). Annual flood depths are expected to increase by up to 0.5 ft in the right flow path, with scour pool depths up to 6- to 8-ft (Figure 3). No existing infrastructure is at risk of being inundated in the right bank floodplain. The activation of this channel is anticipated to reduce annual velocities in the left (mainstem) channel by up to 3 ft/s, respectively (Figures 3 & 4), effectively reducing stream power and sediment transport capacity. Under the modeled conditions, flow reductions are not expected to result in fish stranding or passage barriers in either flow path (Figure 3). In addition to reducing flow velocities in the existing channel, the proposed structures will create holding areas for adult fish and cover for juveniles. The risk to existing habitat associated with the proposed project work is low.

Infrastructure directly affected in the project reach includes Mosquito Lake Road Bridge, Mosquito Lake Road, and the old steelhead hatchery acclimation ponds. Due to the backwatering effect of the most upstream ELJs, no net changes to flow velocities or sediment mobility are expected through the Mosquito Lake Road bridge crossing, thus no increased pier scour of the bridge footings is anticipated. One hundred-year water surface elevations are not expected to increase under the

bridge, and freeboard between the water surface and bridge will remain greater than 15 ft. The risk of damage to the bridge relative to existing conditions is low. 100-year flood depths may rise up to 0.1 ft along the old steelhead hatchery access road and there is no expected change in 10-year flood depths. No inundation of the acclimation ponds is anticipated under any of the modeled conditions. While the proposed ELJ layout may deflect flow to the west and increase erosion of the left bank adjacent to the ponds there is a 160 ft forested buffer between the active channel and ponds and channel migration is not expected to breach this buffer.

In the right split channel, Whatcom County Public Works has previously relocated the road and contributed to the construction of LW structures along a high eroding slope that forms the right bank of the channel in this area. During the preliminary design process, four additional ELJs were located in this area to mitigate for the increase in flow within the right channel and deflect flows west towards floodplain channels within the interior of the forested island. Results for the hydraulic model updates show a general reduction in velocities along the existing unstable slope. For the 10-year flood under existing conditions, thalweg velocities peak at approximately 11 ft/s and are reduced to a peak of 9.5 ft/s under proposed conditions with an average thalweg velocity reduction in the vicinity of 2 ft/s. Velocities along the toe of the bluff are reduced from an average of 1.8 ft/s to 0.9 ft/s, reducing erosion risk to Mosquito Lake Road. Shear stress is reduced along the toe of the bluff by 0.2-1 lbs/ft<sup>2</sup> which equates to a greater than 50% reduction in shear stress at some locations. This same reduction in velocities and shear stress is observed during the 100-year flood as well. These results indicate the construction of both Phase 1 and 4 projects will reduce the risk of erosion that could threaten Mosquito Lake Road in this area. However, if only Phase 1 is completed (as intended in the summer of 2016), for the period of time following Phase 1 construction to the completion of Phase 4 construction, this area will either remain at current risk levels or at slightly elevated risk levels due to the increased flow into the right split caused by Phase 1 project elements. The repositioning of ELJs 1-2-1 and 1-2-2 is anticipated to mitigate for this effect and can be evaluated with future modeling efforts. In addition, the actual increase in risk in this area will be dependent on future high flows that activate the right split channel near RM 4.9 during this period.

Infrastructure indirectly affected includes Porter Creek Bridge along Mosquito Lake Road. Given the elevation of the Porter Creek Bridge relative to water surfaces elevations along the Middle Fork, the project as proposed is not expected to influence hydraulics or scour through the bridge opening. Construction equipment accessing the Phase 1 and 4 project area will need to adhere to weight restrictions provided by the Whatcom County Public Works Department.

## ELJ Impacts on Channel Migration

Existing natural wood accumulations have effectively diverted flow when jams form, causing unchecked channel migration due to the limited amount of large, stable large wood in the Middle Fork. The quantity and distribution of the proposed ELJs is intended to encourage habitat and pool formation while reducing the potential for future channel migrations that may pose risks to forest development and available fish habitat. The project reach currently has high avulsion potential and is prone to rapid channel migrations as evidenced by recent avulsions in the past 20-years. The short-term channel response to ELJ placements is likely to include bank erosion and bed scour adjacent to the structures due to deflection of flows. The additional sediment and wood from bank erosion is expected to accumulate in the lee of ELJs, backwater areas of reduced velocity, and on downstream structures. Short term, localized changes at each structure may be amplified as the channel adjusts to the flow alignments encouraged by the ELJs and sediment and wood are redistributed. In the long term, the design collectively makes channel-forming processes more predictable by partitioning



flows, lengthening the channel, and introducing roughness, reducing stream power throughout the reach. The stable hard points created will also allow for the development of forested islands in the lee of ELJs, providing shade, wildlife habitat, and vegetative bank stability. It is possible that future aggradation in the left channel could result in a partial avulsion due to changes in hydraulic head induced by increases in water surface elevations relative to the right channel alignment. Phase 4 ELJs are intended to balance aggradation throughout both flow paths, reducing the risk of a full avulsion.

## Potential Impacts to Recreational Users

Due to the dynamic nature of the river and mass delivery of sediment and large wood upstream of the project reach, the Lower Middle Fork is moderately dangerous under existing conditions. Frequent channel migrations and partial channel avulsions are part of the river's current geomorphic regime. The dynamic response of the river to these changes makes recreational safety and boater navigation slightly unpredictable at present. Although the proposed work includes large wood additions to the channel, these structures are not projected to become mobilized under the range of flows in the Middle Fork. Wood debris jams are considered natural features in western Washington fluvial systems. Large wood presence in the Middle Fork poses a hazard to recreational users regardless of the restoration work. The efficiency of ELJs in capturing additional wood may increase the risk for inexperienced boaters; however, the structures will increase the overall stability and predictability of the channel form relative to existing conditions. The addition of ELJ structures will enhance channel complexity, requiring boaters to be more aware of obstructions and flow patterns. Wood placements will also create areas of slow moving backwater, which may increase boater response times and the number of available pullouts.

Many recreational boaters on the Middle Fork commonly take out near the Mosquito Lake Road Bridge upstream of the project site. Public outreach regarding the proposed work should be implemented to aid boaters in understanding any changes in safety and channel form. Posting orange warning signs on each engineered wood placement may help boaters recognize and navigate around flow obstructions. Warning signs can be placed at known launch points upstream or within the project reach that indicate the river has natural and engineered wood debris that should be avoided. The same signage can also note facts about the restoration project and other conditions that may pose a hazard such as areas of constricted, fast-moving water. Correspondence and public meetings with river guides and recreational groups known to use the river can also improve safety by educating users and thus reduce risk.

## Risks of a No-Action Alternative

Due to historic losses of riparian forest and the removal of large wood from the Middle Fork, the project reach is subject to frequent and sudden disturbances (NSD 2013). The proposed restoration is intended to expedite the system's recovery and reverse historic trends in channel incision, rapid channel migration, and frequent avulsions, in order to create a more stable river and higher quality habitat. Without restoration, the Middle Fork is expected to continue incising, lowering the water surface and further disconnecting floodplain and side channel habitats. As the channel becomes more entrenched in a simplified channel, stream power is expected to increase, exacerbating incision and erosional processes. In the project reach, channel instability will result in the ongoing loss of developing riparian forest as the channel continues to migrate in the absence of stable hard points and forested islands. The recruitment of young successional forest will not limit channel migration rates, or contribute to stable wood accumulations. Active channel migration at the Bear and Peat



Bog Creek tributaries would be expected to continue, further reducing spawning opportunities in this high value habitat. There is also a risk of continued loss of spawning gravels, pools, and edge habitat due to the increased shear stress associated with an incised channel.

## Limitations

We have prepared this report for the Lummi Natural Resource Department, their authorized agents and regulatory agencies responsible for the Middle Fork restoration project. Within the limitations of scope, schedule and budget, our services have been executed in accordance with generally accepted practices for river restoration and the engineered placement of wood in this area at the time this report was prepared. The conclusions, recommendations, and opinions presented in this report are based on our professional knowledge, judgment and experience. No warranty or other conditions, expressed or implied, should be understood.

We appreciate this opportunity to be of service to the Nooksack Salmon Enhancement Association for this project and look forward to continuing to work with you. Please call if you have any questions regarding this report, or if you need additional information.

Sincerely,

Natural Systems Design, Inc.



R. Leif Embertson, MS, PE, CFM  
Senior River Engineer



Tim Abbe, PhD, PEG, PHG  
Principal Geomorphologist

### Attachments:

- Figure 1 – Project reach map
- Figure 2 – Example Type-3 ELJ
- Figure 3 – Change in flow depth during 1-yr flow
- Figure 4 – Change in flow velocity during 1-yr flow
- Figure 5 – Change in flow shear stress during 1-yr flow
- Figure 6 – Change in flow depth during 10-yr flow
- Figure 7 – Change in flow velocity during 10-yr flow
- Figure 8 – Change in water surface elevation during 100-yr flow

Appendix A - Final Design Drawings

Appendix B - Final Design Cost Estimate

## REFERENCES

- Abbe, T.B. 2000. Patterns, mechanics, and geomorphic effects of wood debris accumulations in a forest river system. Ph.D. dissertation, University of Washington, Seattle, WA, 219pp.
- Abbe, T., G. Pess, D. Montgomery, K. Fetherston. 2003. Integrating Engineered Log Jam Technology into River Rehabilitation. in Restoration of Puget Sound Rivers. University of Washington Press.
- Abbe, T., Kennard, P., Park, J., and Beason, S. 2008. Alluvial landscape response to climate change in glacial rivers and the implications to transportation infrastructure. National Hydraulic Engineering Conference, Federal Highways Administration. Portland, ME.
- Brauderick, C.A., Grant, G.E., 2000. When do logs move in rivers? Water Resources Research, Vol 36, pp 571-83.
- Bureau of Reclamation, Pacific Northwest Region Resource & Technical Services, Large Woody Material – Risk Based Design Guidelines, September, 2014.
- Chase, K. and S. Holnbeck. 2003. Evaluation of Pier-Sour Equations for Coarse-Bed Streams. US Geological Survey Scientific Investigations report 2004-5111.
- D'Oust, S.G.D. and Millar, R.G. 2000. Stability of ballasted woody debris habitat structures. Journal of Hydraulic Engineering, Vol 126, pp. 810-17
- Federal Highway Administration (FHWA), Hydraulic Engineering Circular No. 20 (HEC-20), Stream Stability at Highway Structures, 3rd Edition, Publication No. FHWA-NHI-01-002 HEC-18, March, 2001
- Federal Highway Administration (FHWA), Hydraulic Engineering Circular No. 18 (HEC-18), Evaluating Scour At Bridges, 5th Edition, Publication No. FHWA-HIF-12-003 HEC-18, April, 2012
- Hamlet, A. F., and D. P. Lettenmaier. 2007. Effects of 20th century warming and climate variability on flood risk in the western U.S., Water Resour. Res., 43, W06427, doi:10.1029/2006WR005099.
- Lagasse, P., J. Schall, E. Richardson. 2001. Stream Stability at Highway Structures, third Edition. Federal Highways Administration HEC-20 Manual.
- Landers, M.N., Mueller, D.S., 1996. Channel scour at bridges in the United States. US Department of Transportation, Federal Highways Administration Publication FHWA RD-95-184, 140p.
- Lee, S., A.F. Hamlet, 2011. Skagit River Basin Climate Science Report, a summary report prepared for Skagit County and the Envision Skagit Project by the Department of Civil and Environmental Engineering and The Climate Impacts Group at the University of Washington.
- Lummi Natural Resources Department. 2011. Middle Fork Nooksack River Habitat Assessment. Lummi Nation.
- Montgomery, D. and T. Abbe. 2006. Influence of logjam-formed hard points on the formation of valley-bottom landforms in an old-growth forest valley, Queets River, Washington, USA. Quaternary Research. Vol. 65:1.
- Mote, P.W., 2006. Climate-driven variability and trends in mountain snowpack in western North America. J. Climate, 19, 6209-6220.

- Mote, P.W., A.F. Hamlet, E. Salathé, 2008. Has spring snowpack declined in the Washington Cascades? *Hydro. Earth Syst. Sci.*, 12, 193-206.
- Natural Systems Design. 2013. Lower Middle Fork Nooksack Geomorphic and Hydraulic Assessment. Prepared for Nooksack Salmon Enhancement Association.
- Natural Systems Design. 2016. Middle Fork Nooksack Geomorphic Assessment Update. Prepared for Lummi Nation Natural Resources.
- Neiman, Paul J., L. J. Schick, F. M. Ralph, M. Hughes, G. A. Wick, 2011. Flooding in Western Washington: The Connection to Atmospheric Rivers. *Journal of Hydrometeorology*, 12, 1337–1358.
- Richardson, E. and S. Davis. 2001. Evaluating Scour at Bridges, Fourth Edition. Federal Highways Administration HEC-18 Manual.
- Shields, F.D., Knight, S.S. et al. 2000. Large woody debris structures for incised channel rehabilitation. Proceedings of ASCE 2000 joint conference on water resources engineering and water resources planning and management. Reston, VA ASCE.
- United States Geological Survey. 2014. Basin Characteristics Report for RM 3.8 of the Middle Fork Nooksack River. StreamStats for Washington State.
- WRIA 1. 2005. Water Resource Inventory Area (WRIA) 1 Salmonid Recovery Plan. Whatcom County, WA.



## FIGURES



1900 N. Northlake Way, Suite 211  
Seattle, WA 98103





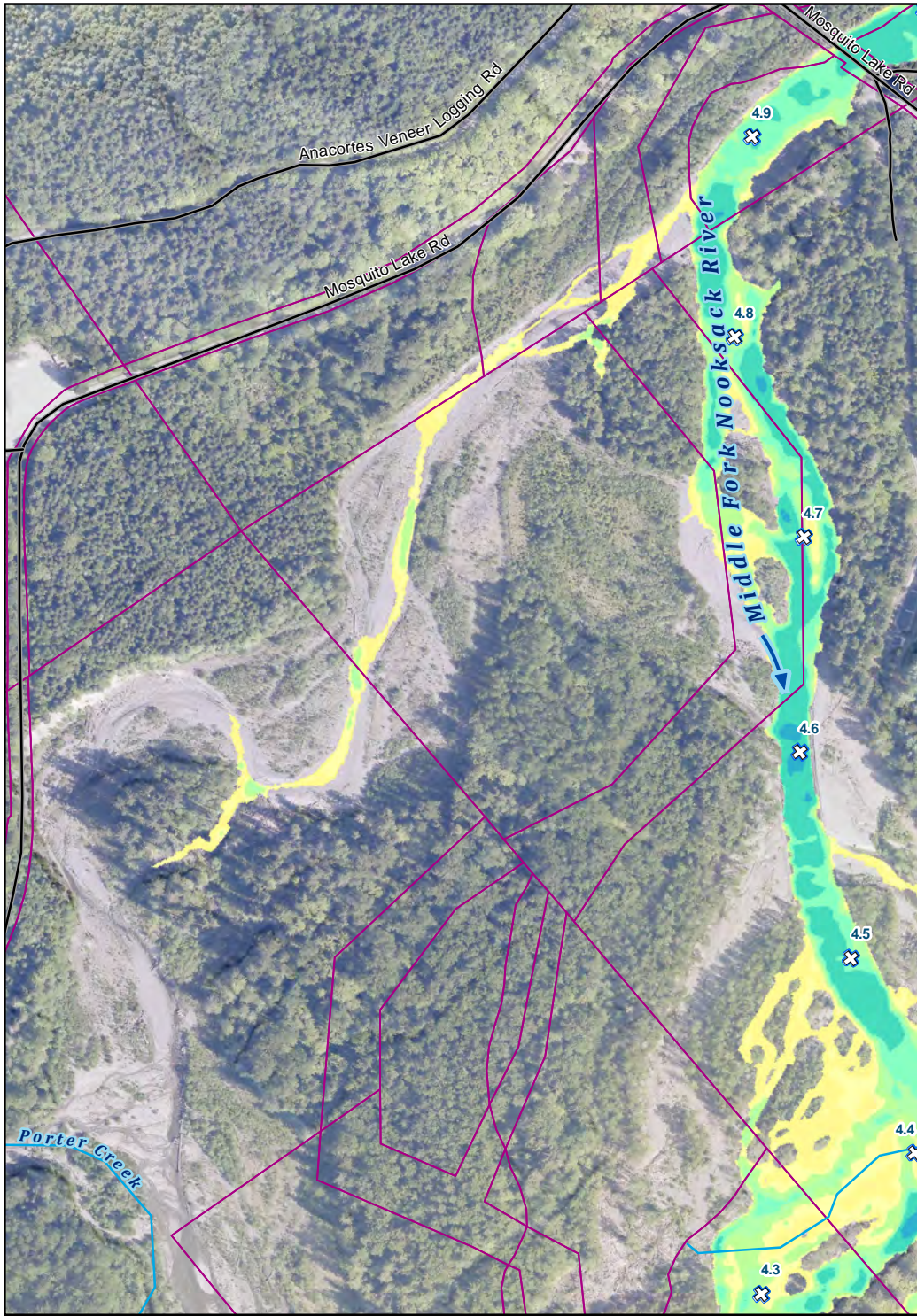




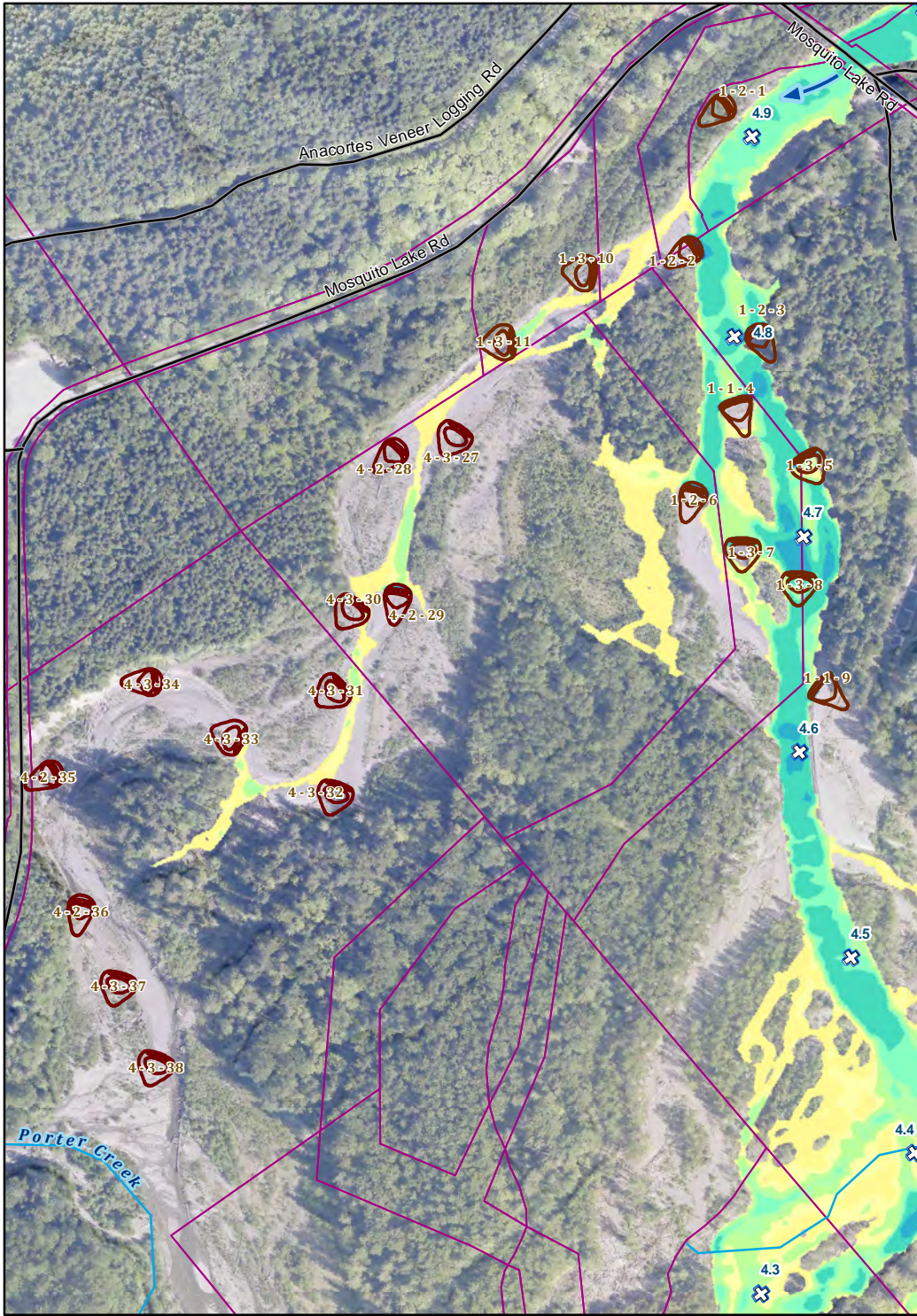
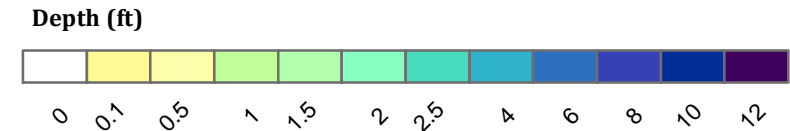
FIGURE 2 – 2013 Aerial photo (GoogleEarth) of constructed pile array ELJs on the Upper Quinault River basin (Top left); Left bank pile array ELJ constructed in 2012 (Lower left); Center channel pile array ELJ constructed in 2012 with significant newly racked mobile LWD (Lower right)

## Middle Fork Nooksack River LWD Preliminary Design

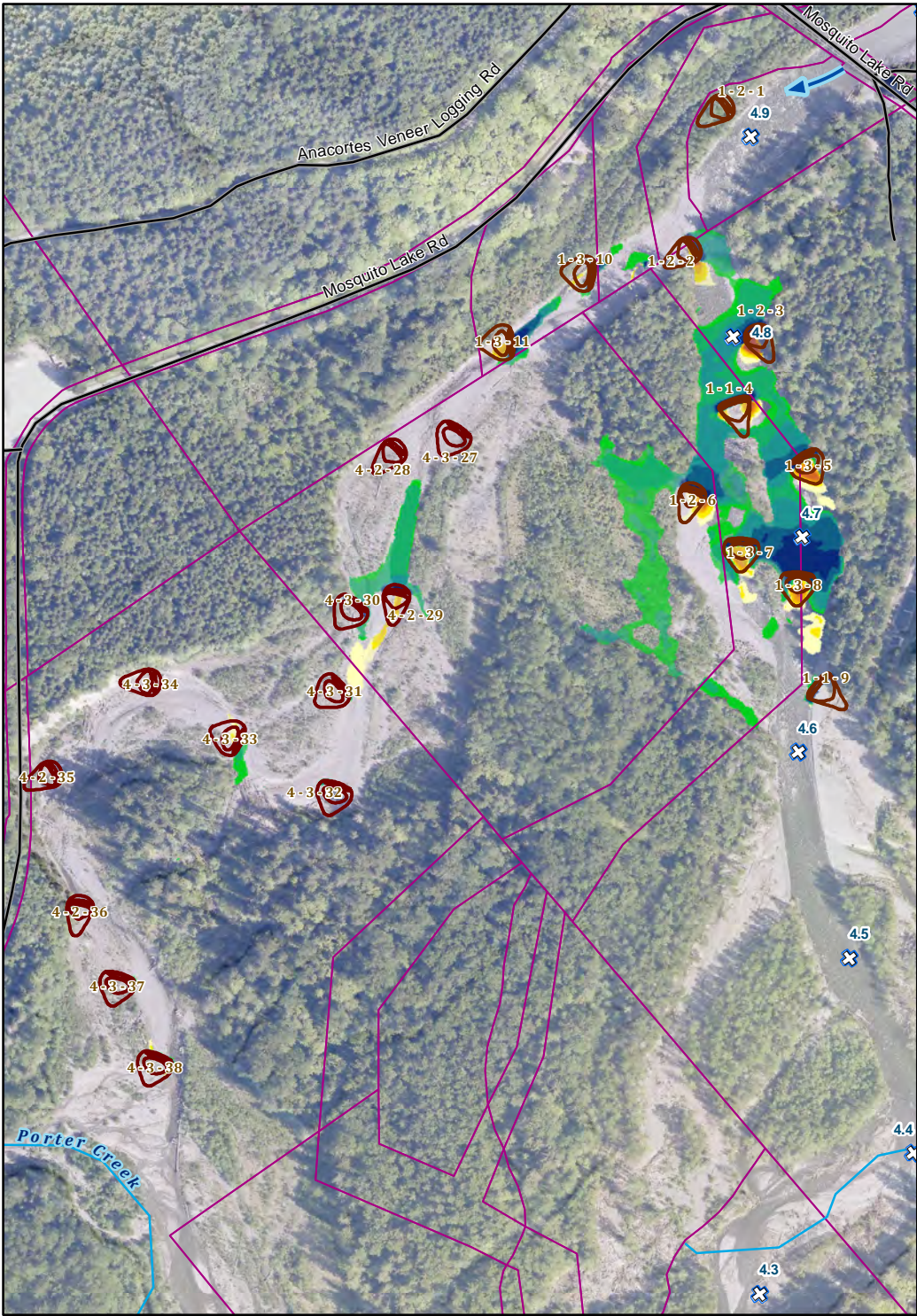
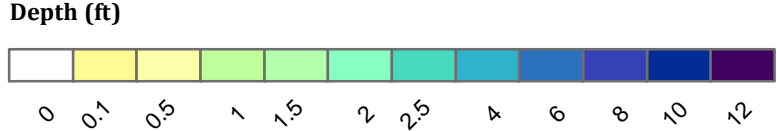




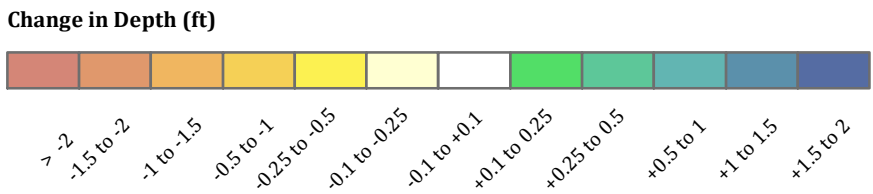
Existing Conditions



Proposed Conditions



Difference



Middle Fork Nooksack River - Porter Creek Reach Restoration Phase 1  
**Figure 3 - 1 year Flow Depths (2,400 cfs)**

Hydronia RiverFlo-2D Hydraulic Model Output for 1 year (2,400 cfs) flow event.  
 Terrain used in hydraulic modeling is representative of 2013 conditions.

Parcels: Whatcom County 2013  
 Roads: US Census Bureau 2010  
 Streams: USGS NHD (1:24,000)  
 River Miles: USGS Topo  
 Aerial: USDA NAIP 2013

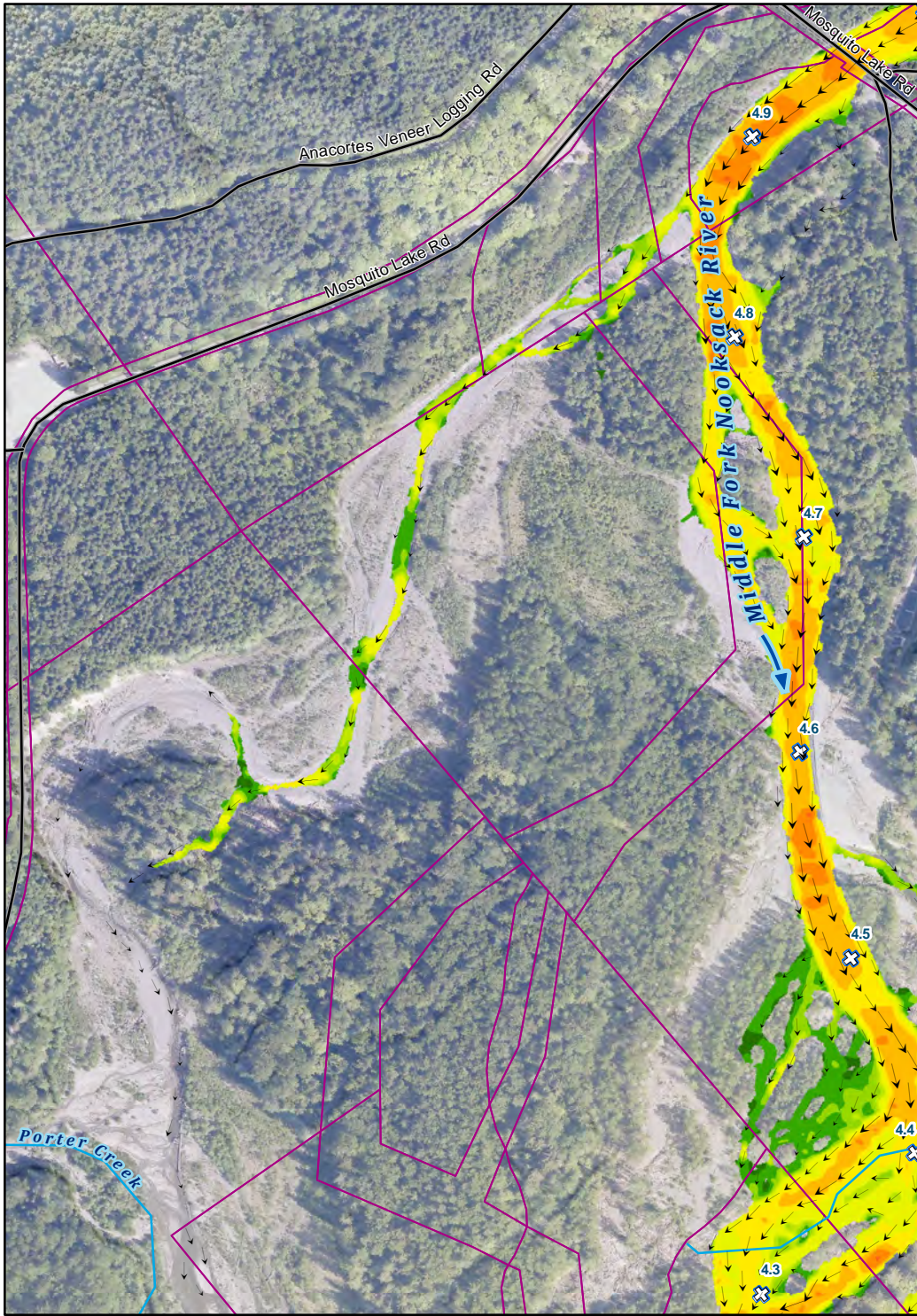
- 15 River Mile Streams
- Roads
- Parcel Boundaries
- Proposed ELJ



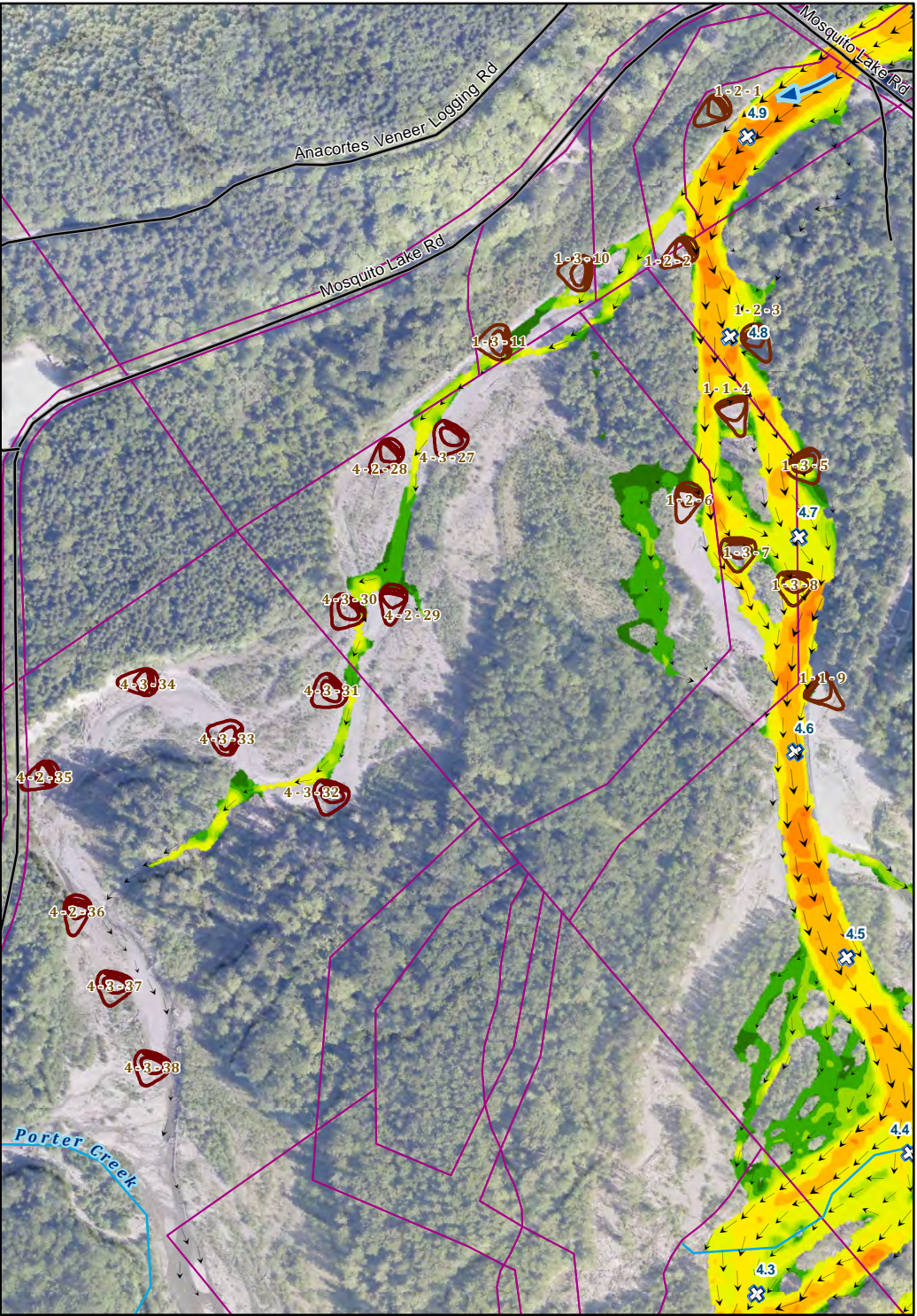
0 500 1,000 1,500 Feet  
 Lambert conformal conic projection, NAD 1983  
 State Plane Coordinate System (WA North Zone)



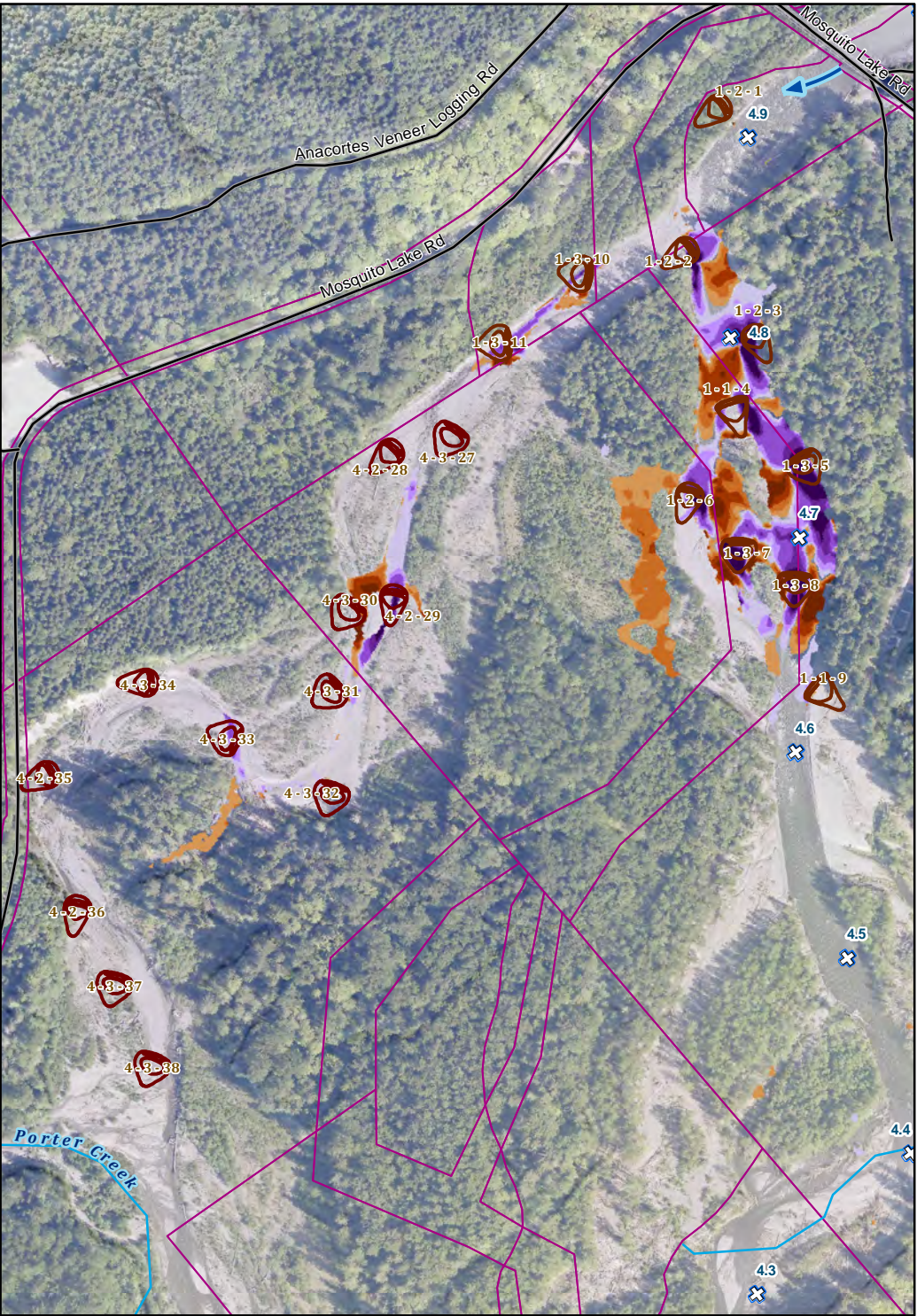
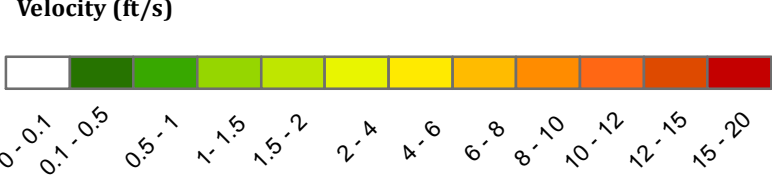




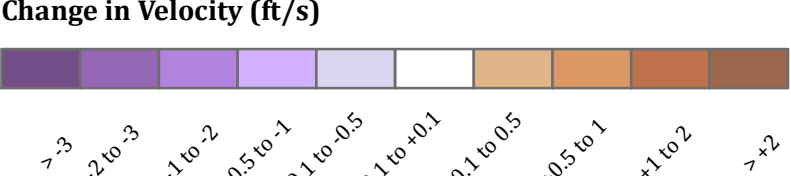
Existing Conditions



Proposed Conditions



Difference

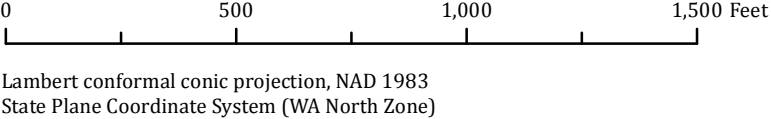


Middle Fork Nooksack River - Porter Creek Reach Restoration Phase 1  
**Figure 4 - 1 year Flow Velocities (2,400 cfs)**

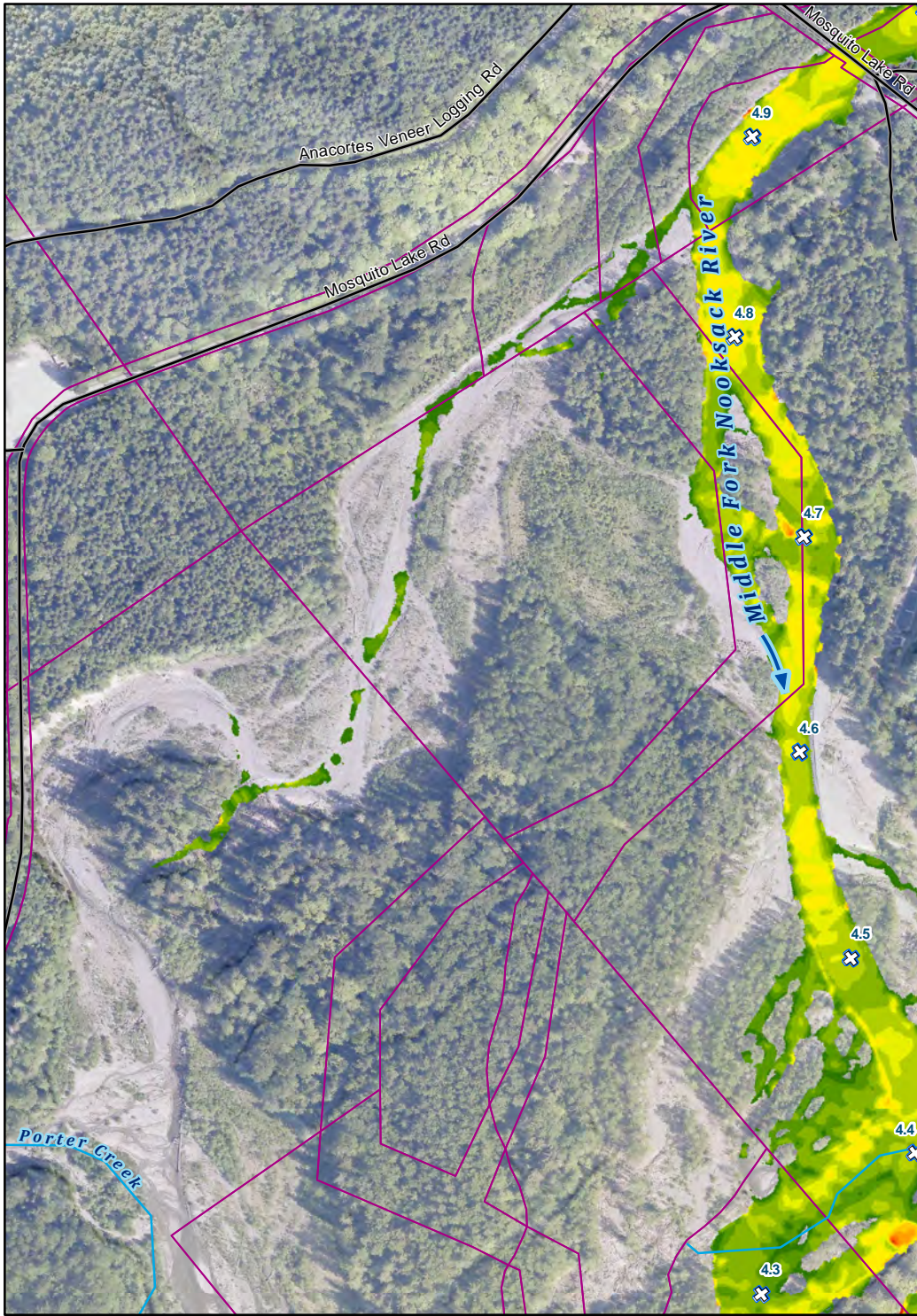
Hydronia RiverFlo-2D Hydraulic Model Output for 1 year (2,400 cfs) flow event.  
 Terrain used in hydraulic modeling is representative of 2013 conditions.

Parcels: Whatcom County 2013  
 Roads: US Census Bureau 2010  
 Streams: USGS NHD (1:24,000)  
 River Miles: USGS Topo  
 Aerial: USDA NAIP 2013

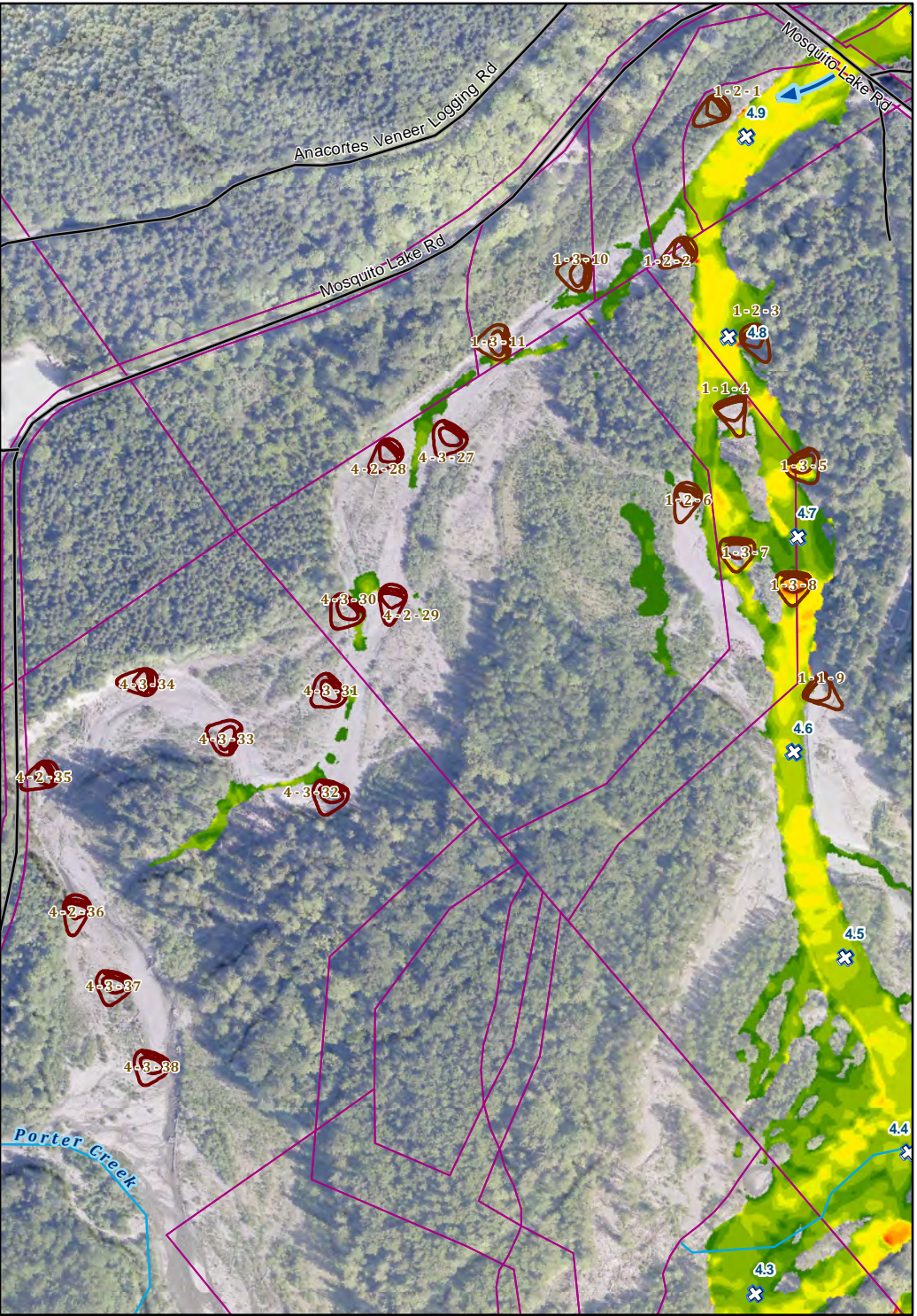
- 15 River Mile Streams
- Roads
- Parcel Boundaries
- Proposed ELJ



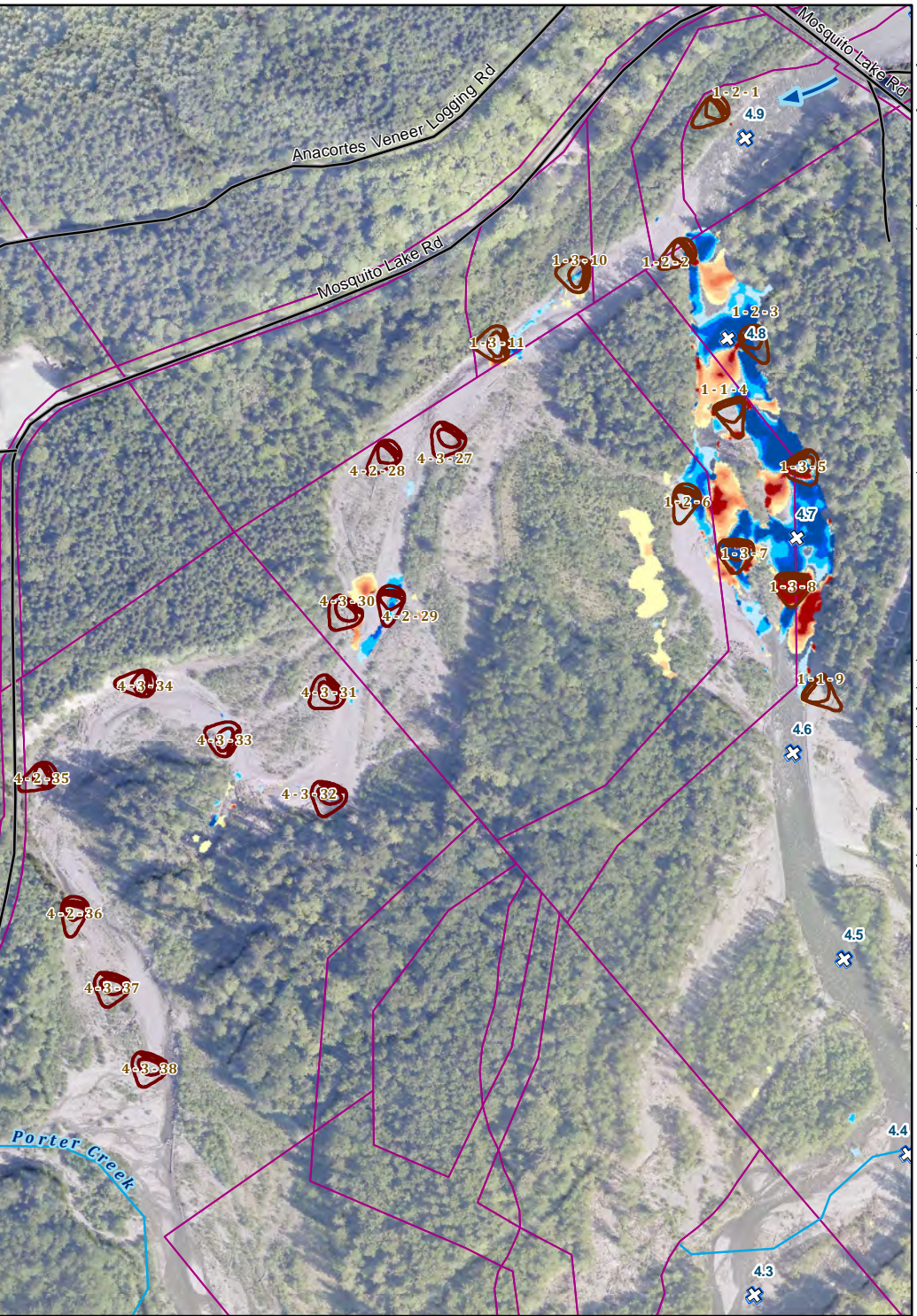




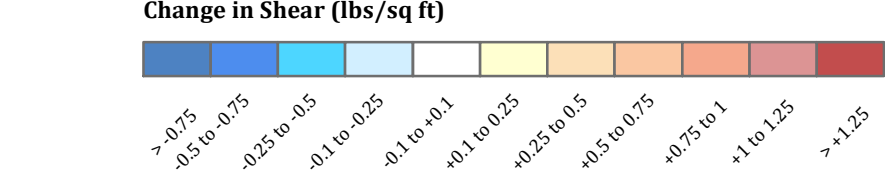
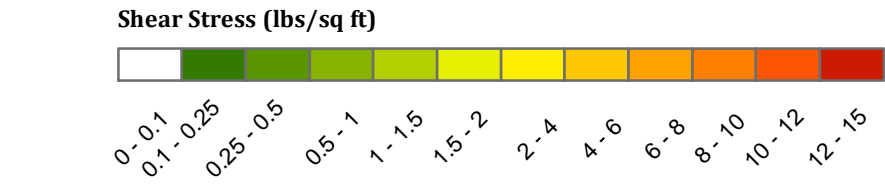
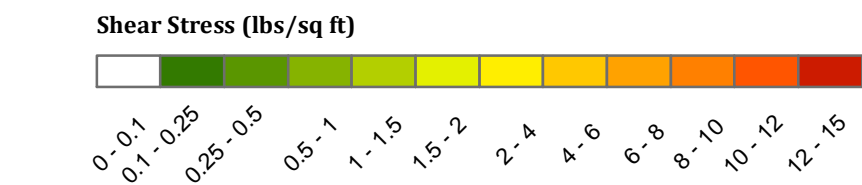
Existing Conditions



Proposed Conditions



Difference



Middle Fork Nooksack River - Porter Creek Reach Restoration Phase 1  
**Figure 5 - 1 year Flow Shear Stress (2,400 cfs)**

Hydronia RiverFlo-2D Hydraulic Model Output for 1 year (2,400 cfs) flow event.  
 Terrain used in hydraulic modeling is representative of 2013 conditions.

Parcels: Whatcom County 2013  
 Roads: US Census Bureau 2010  
 Streams: USGS NHD (1:24,000)  
 River Miles: USGS Topo  
 Aerial: USDA NAIP 2013

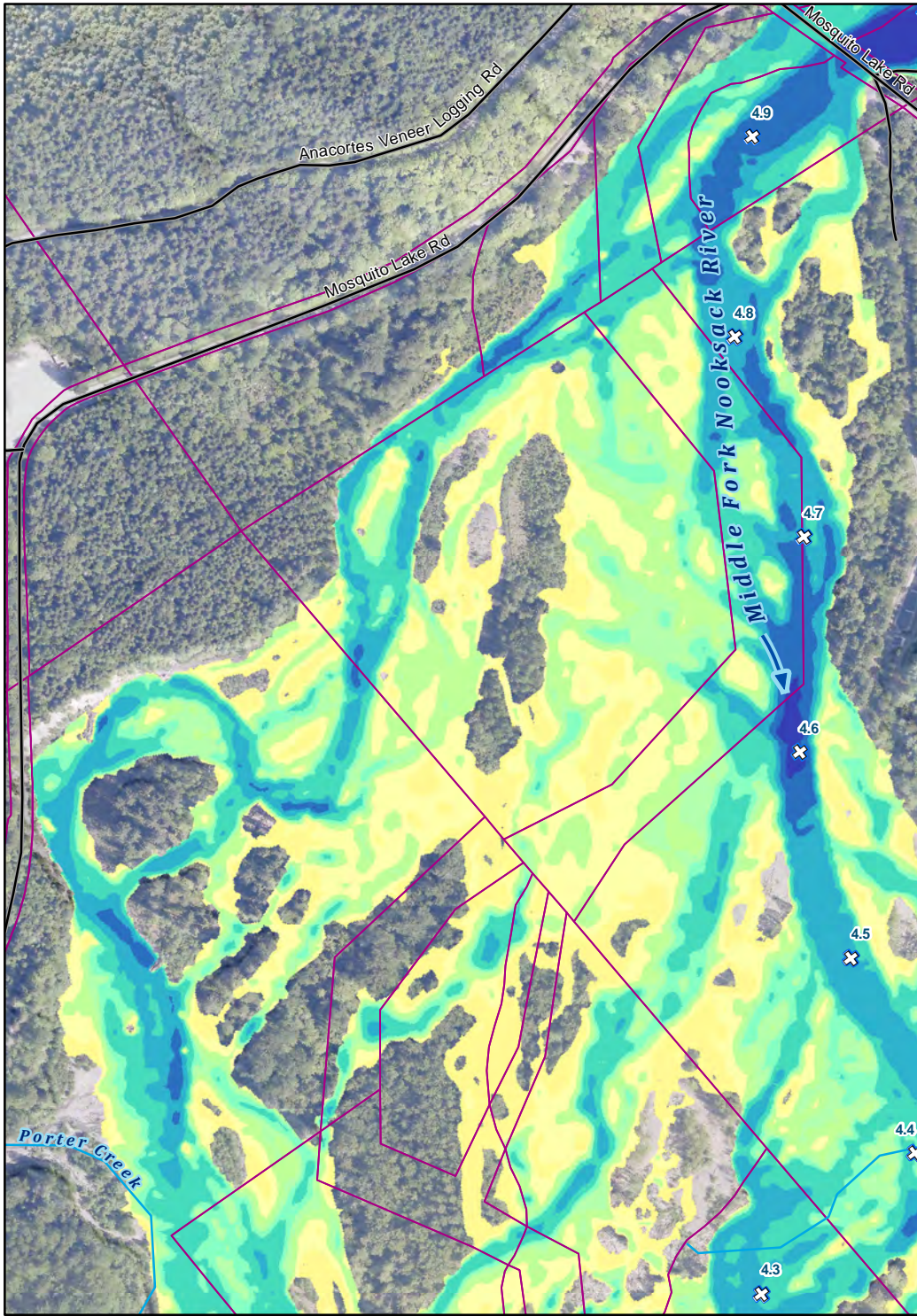
- River Mile Streams
- Roads
- Parcel Boundaries
- Proposed ELJ



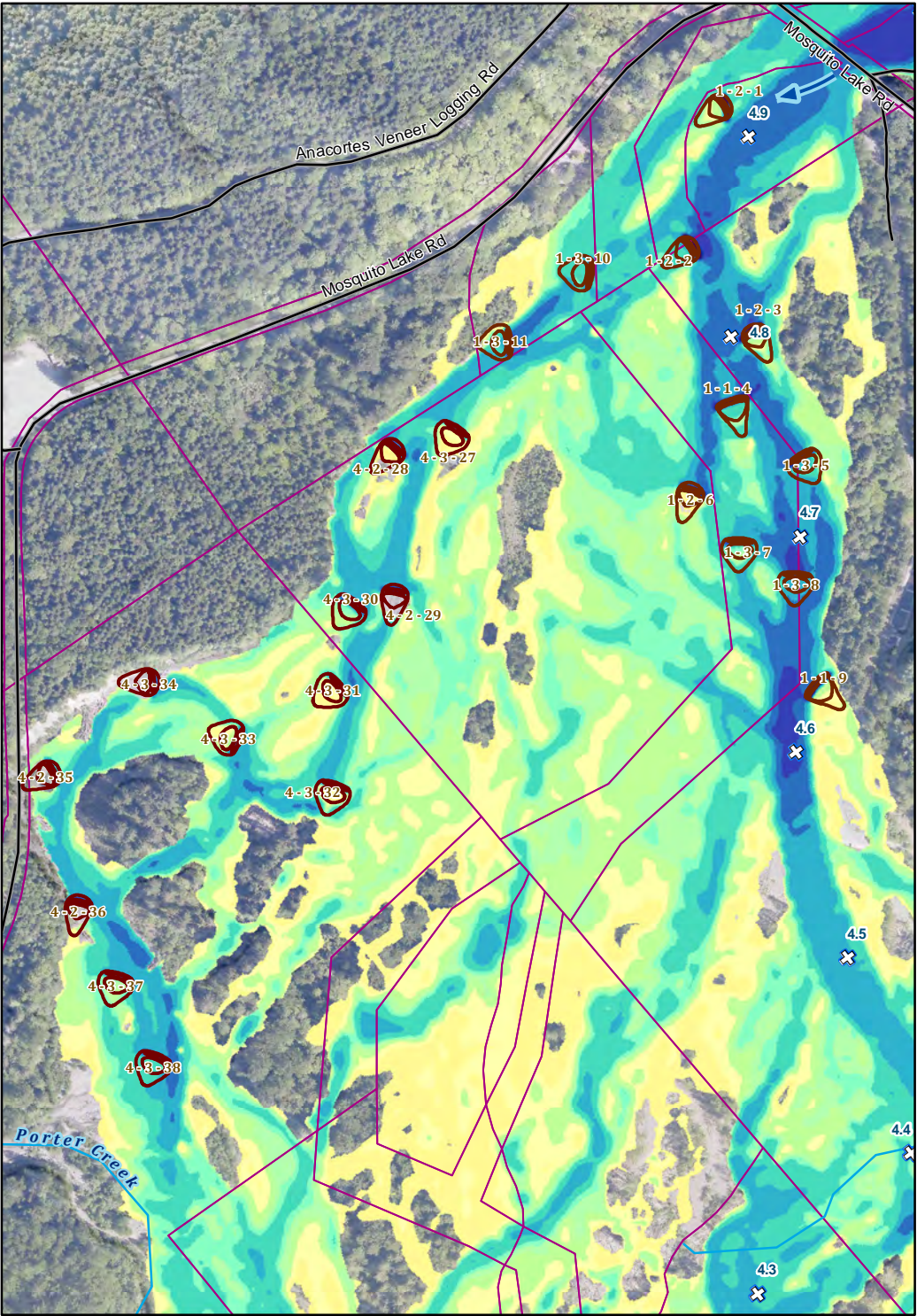
0 500 1,000 1,500 Feet  
 Lambert conformal conic projection, NAD 1983  
 State Plane Coordinate System (WA North Zone)



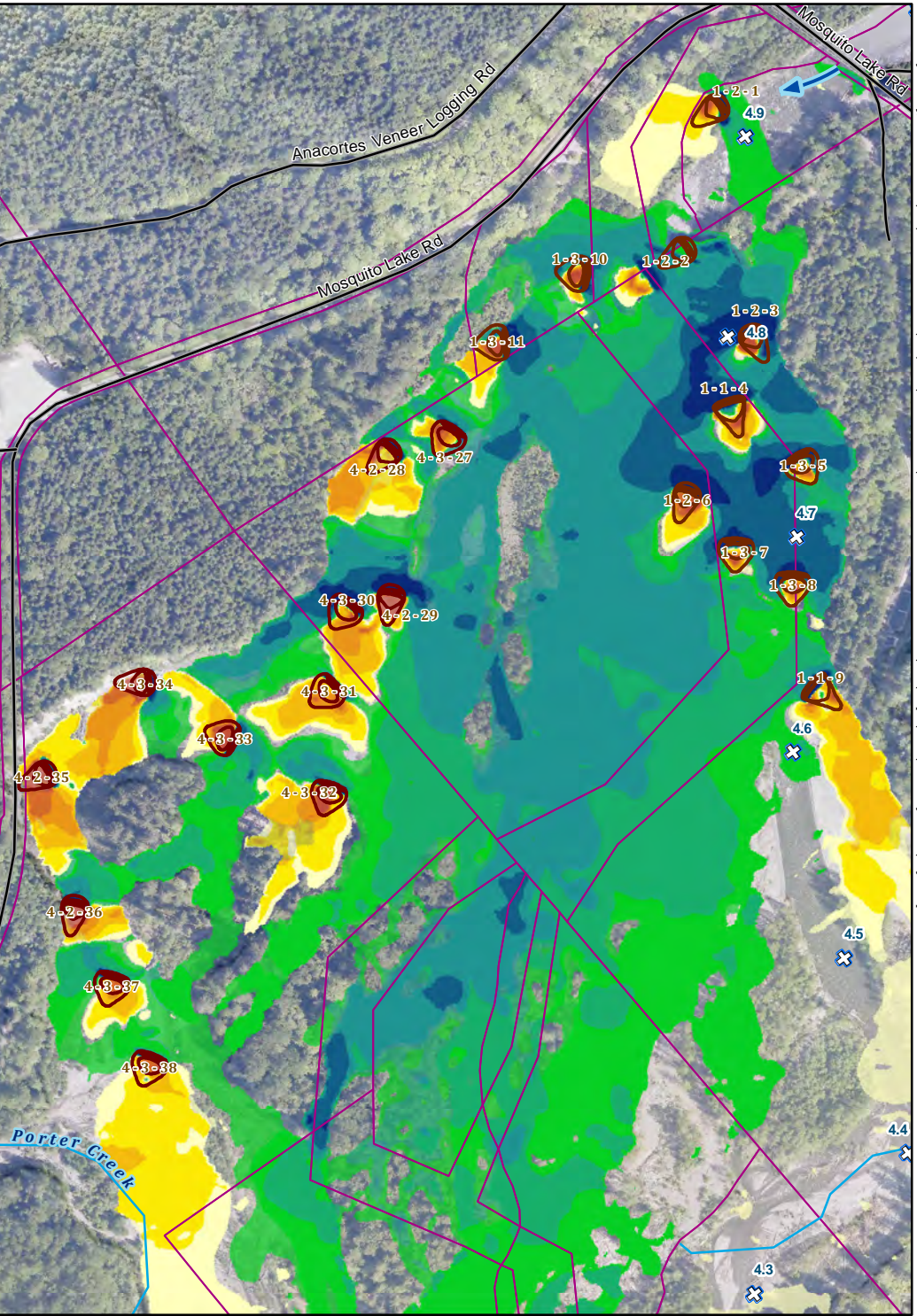




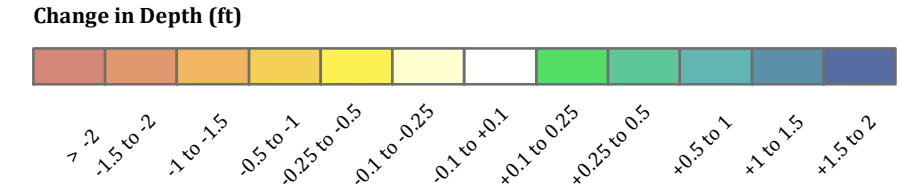
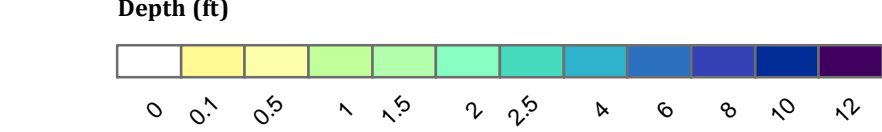
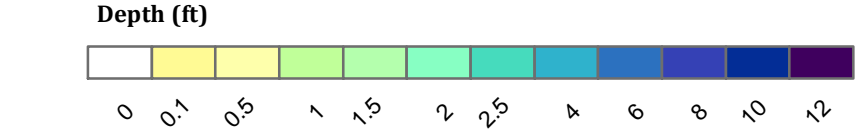
Existing Conditions



Proposed Conditions



Difference

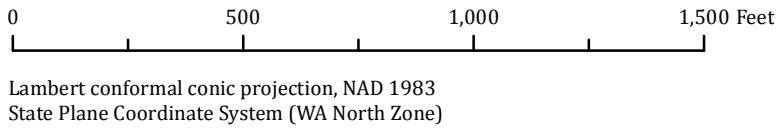


Middle Fork Nooksack River - Porter Creek Reach Restoration Phase 1  
**Figure 6 - 10 year Flow Depths (14,900 cfs)**

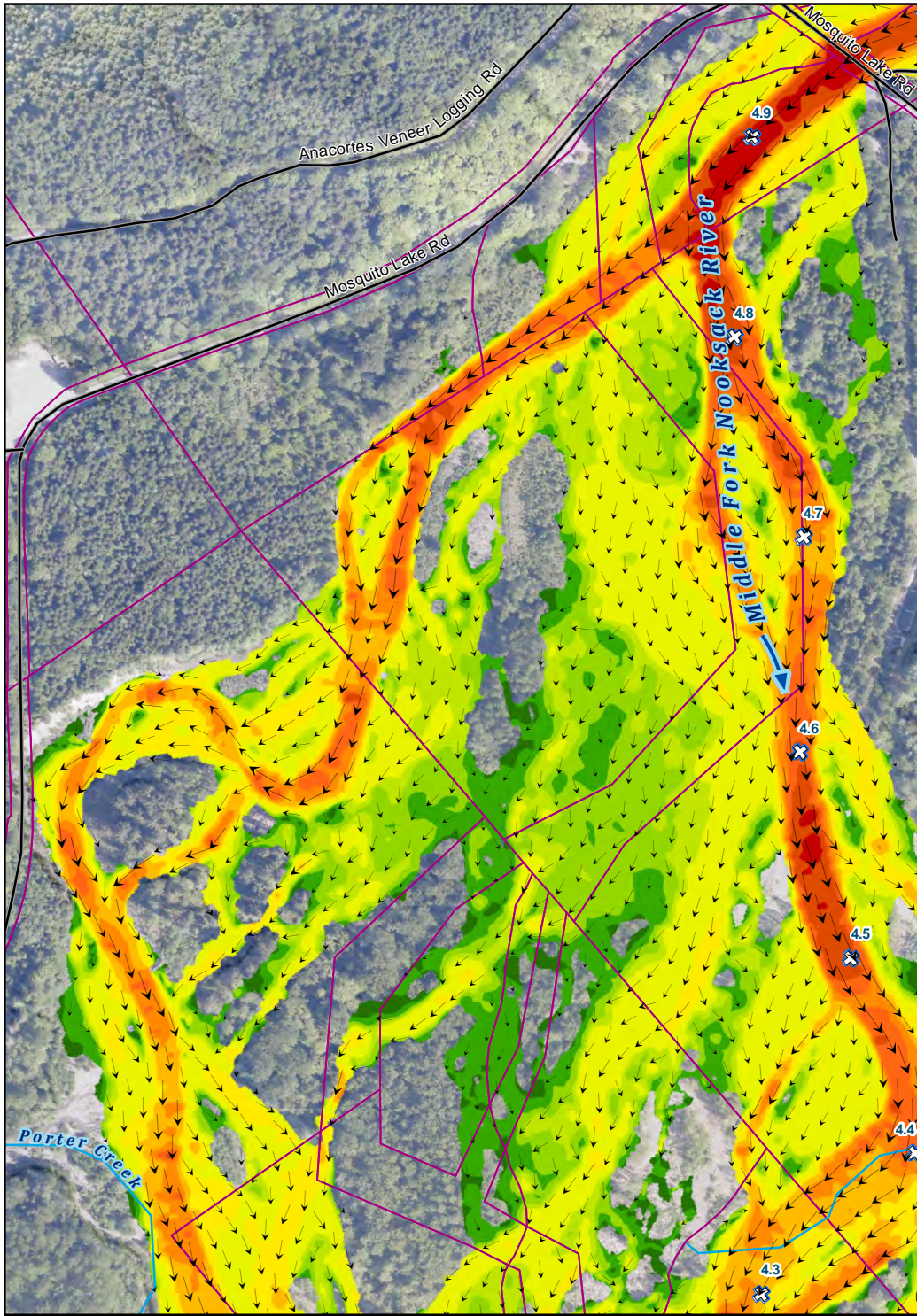
Hydronia RiverFlo-2D Hydraulic Model Output for 10 year (14,900 cfs) flow event.  
 Terrain used in hydraulic modeling is representative of 2013 conditions.

Parcels: Whatcom County 2013  
 Roads: US Census Bureau 2010  
 Streams: USGS NHD (1:24,000)  
 River Miles: USGS Topo  
 Aerial: USDA NAIP 2013

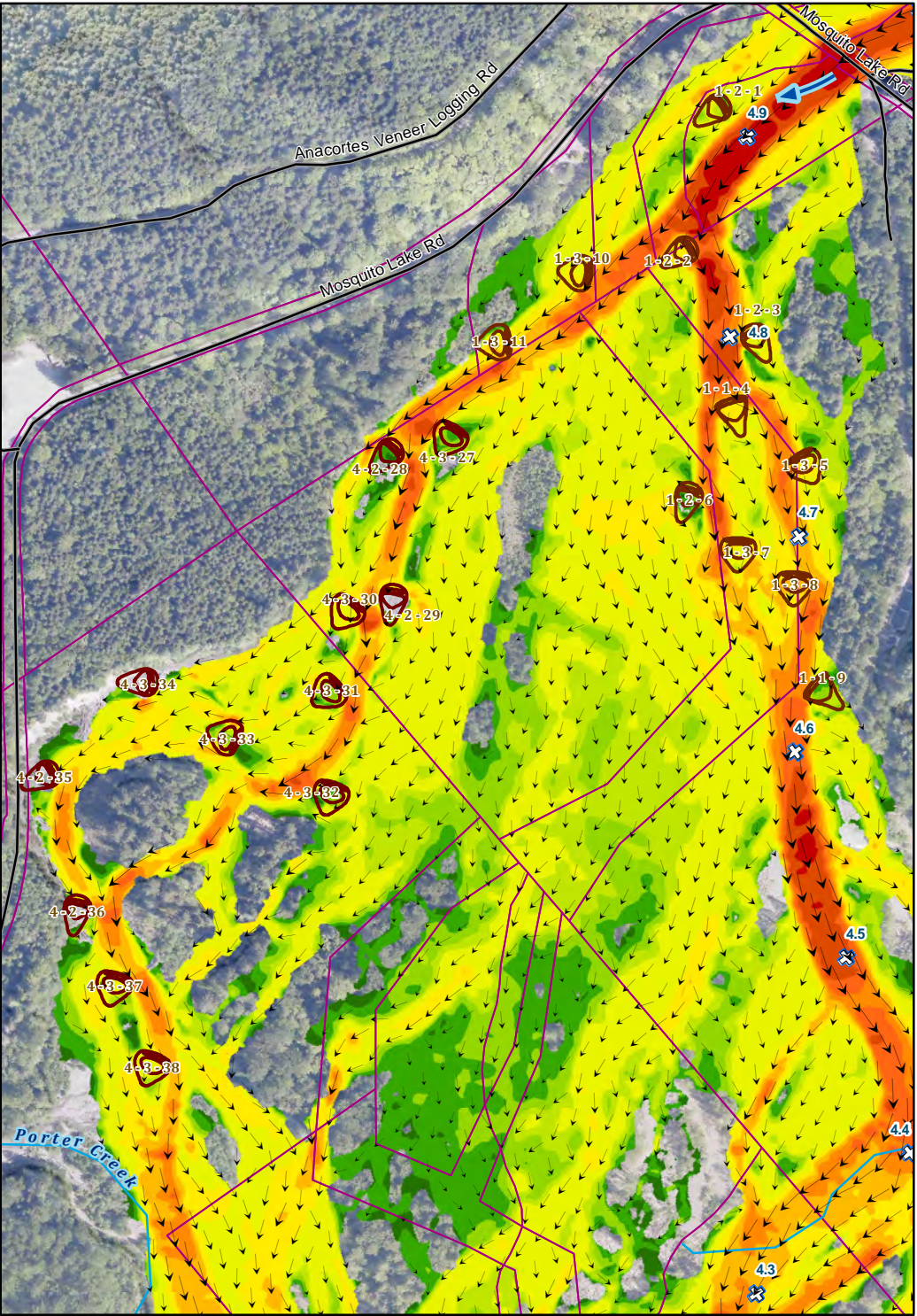
- 15 River Mile Streams
- Roads
- Parcel Boundaries
- Proposed ELJ



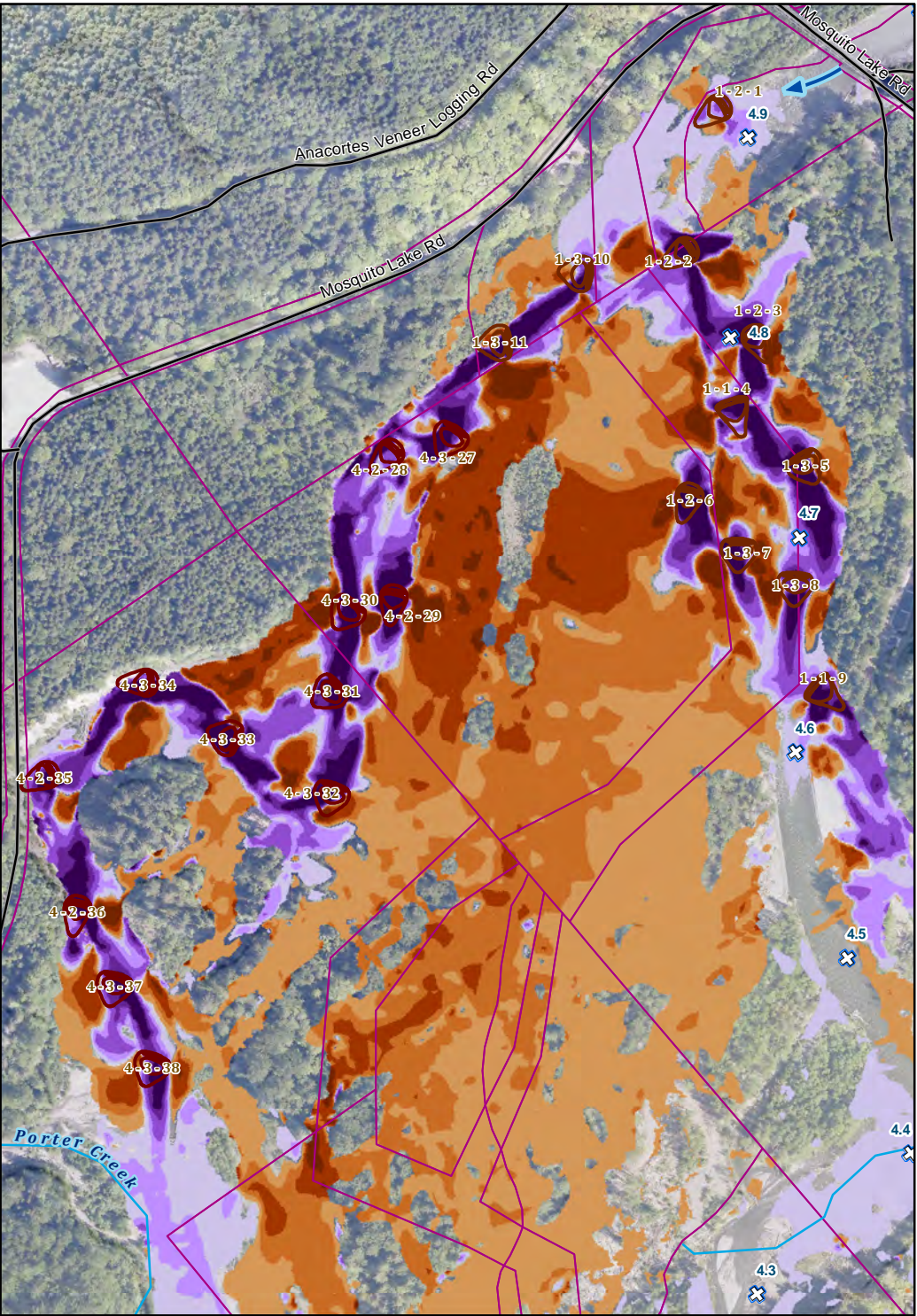
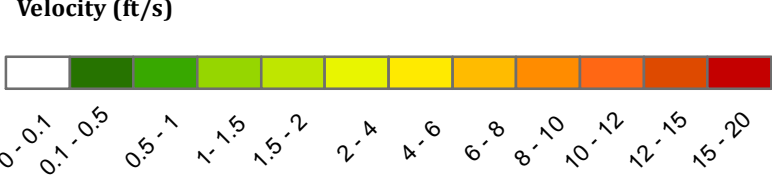




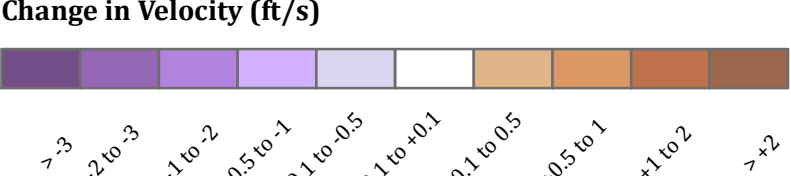
Existing Conditions



Proposed Conditions



Difference

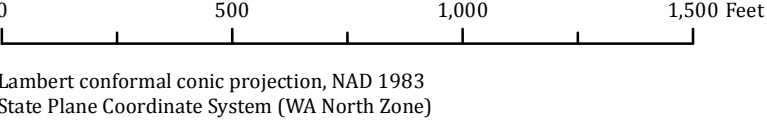


Middle Fork Nooksack River - Porter Creek Reach Restoration Phase 1  
**Figure 7 - 10 year Flow Velocities (14,900 cfs)**

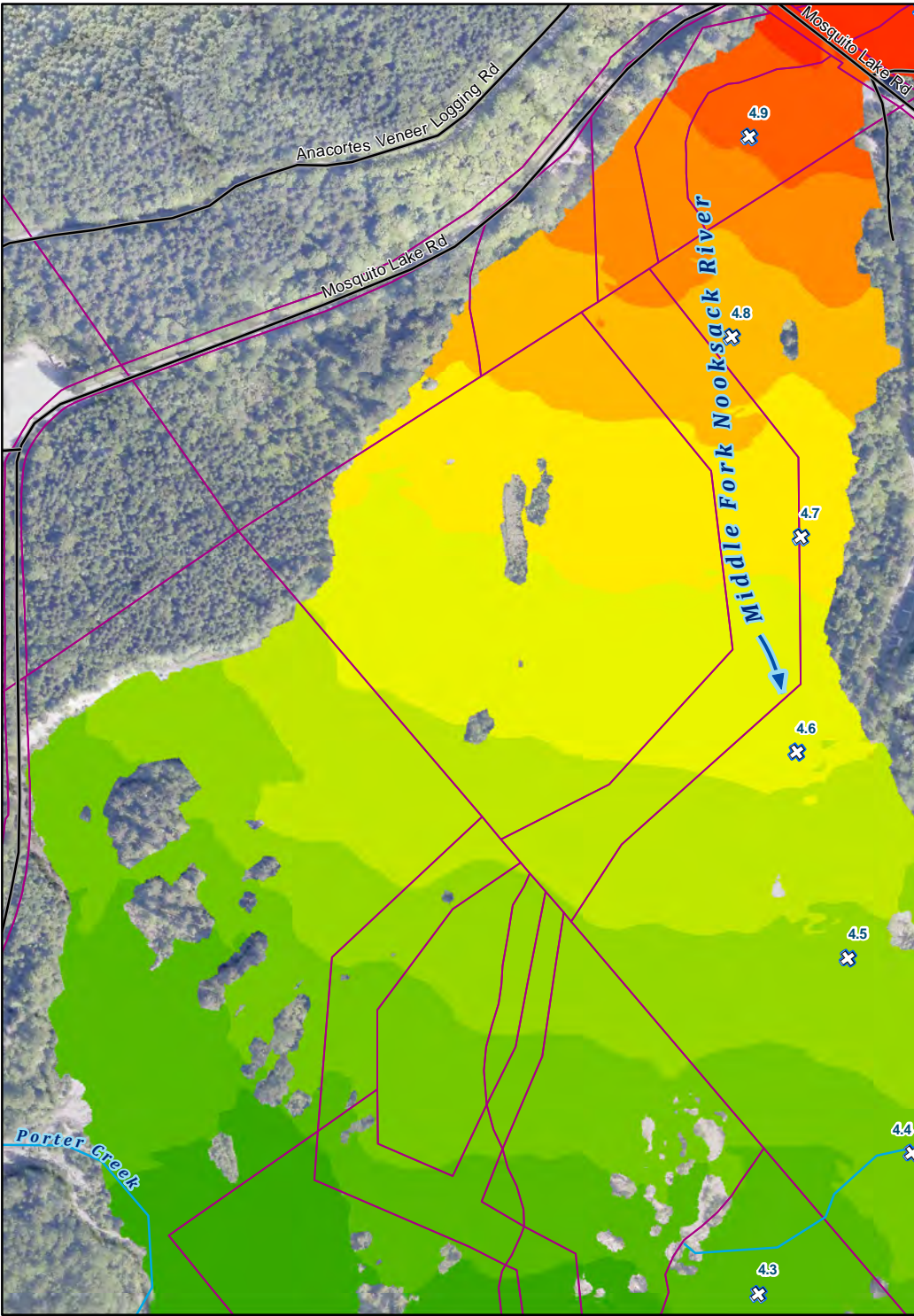
Hydronia RiverFlo-2D Hydraulic Model Output for 10 year (14,900 cfs) flow event.  
 Terrain used in hydraulic modeling is representative of 2013 conditions.

Parcels: Whatcom County 2013  
 Roads: US Census Bureau 2010  
 Streams: USGS NHD (1:24,000)  
 River Miles: USGS Topo  
 Aerial: USDA NAIP 2013

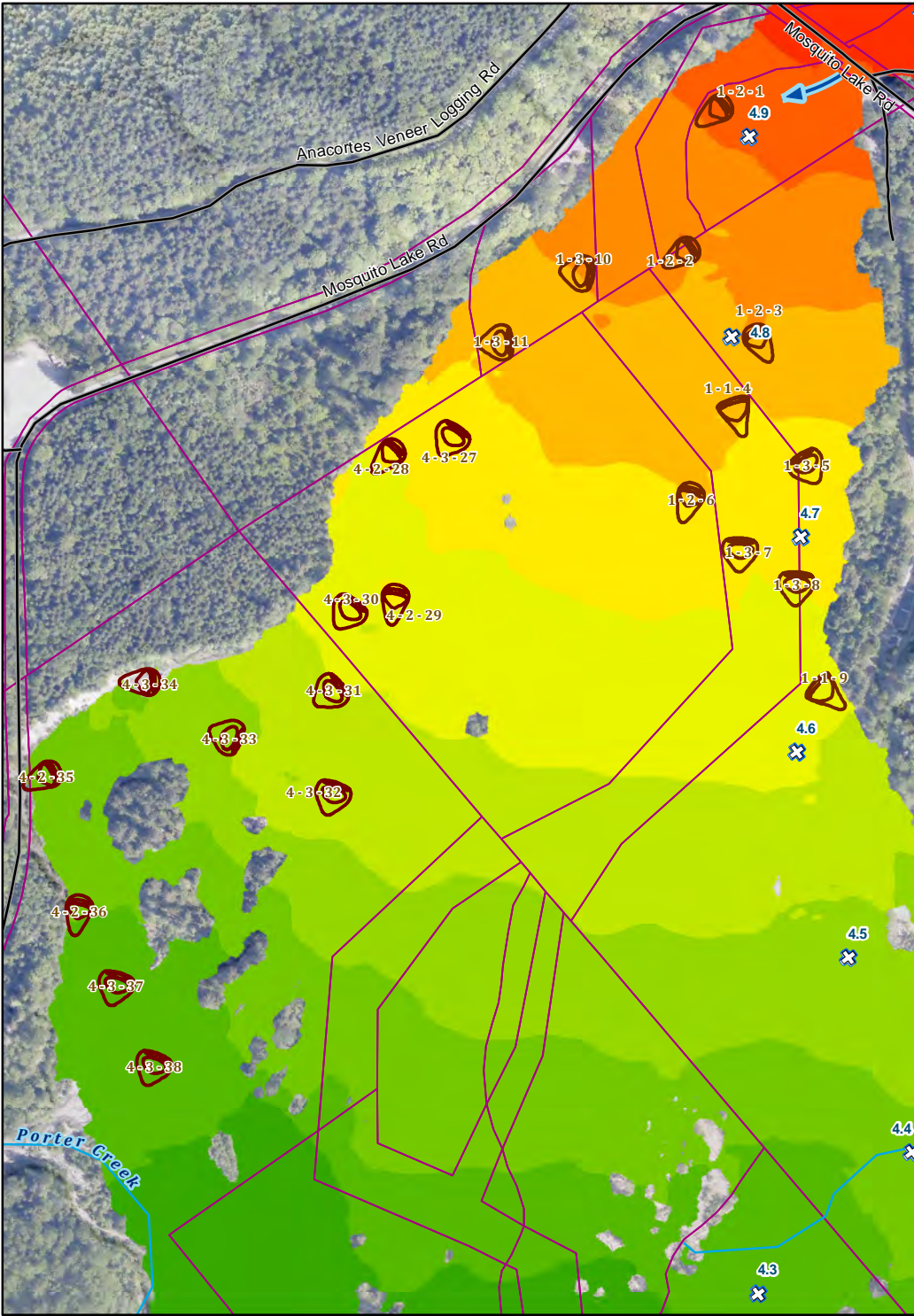
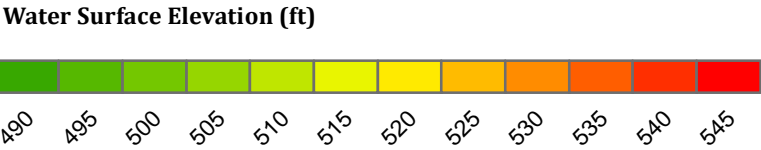
- 15 River Mile Streams
- Roads
- Parcel Boundaries
- Proposed ELJ



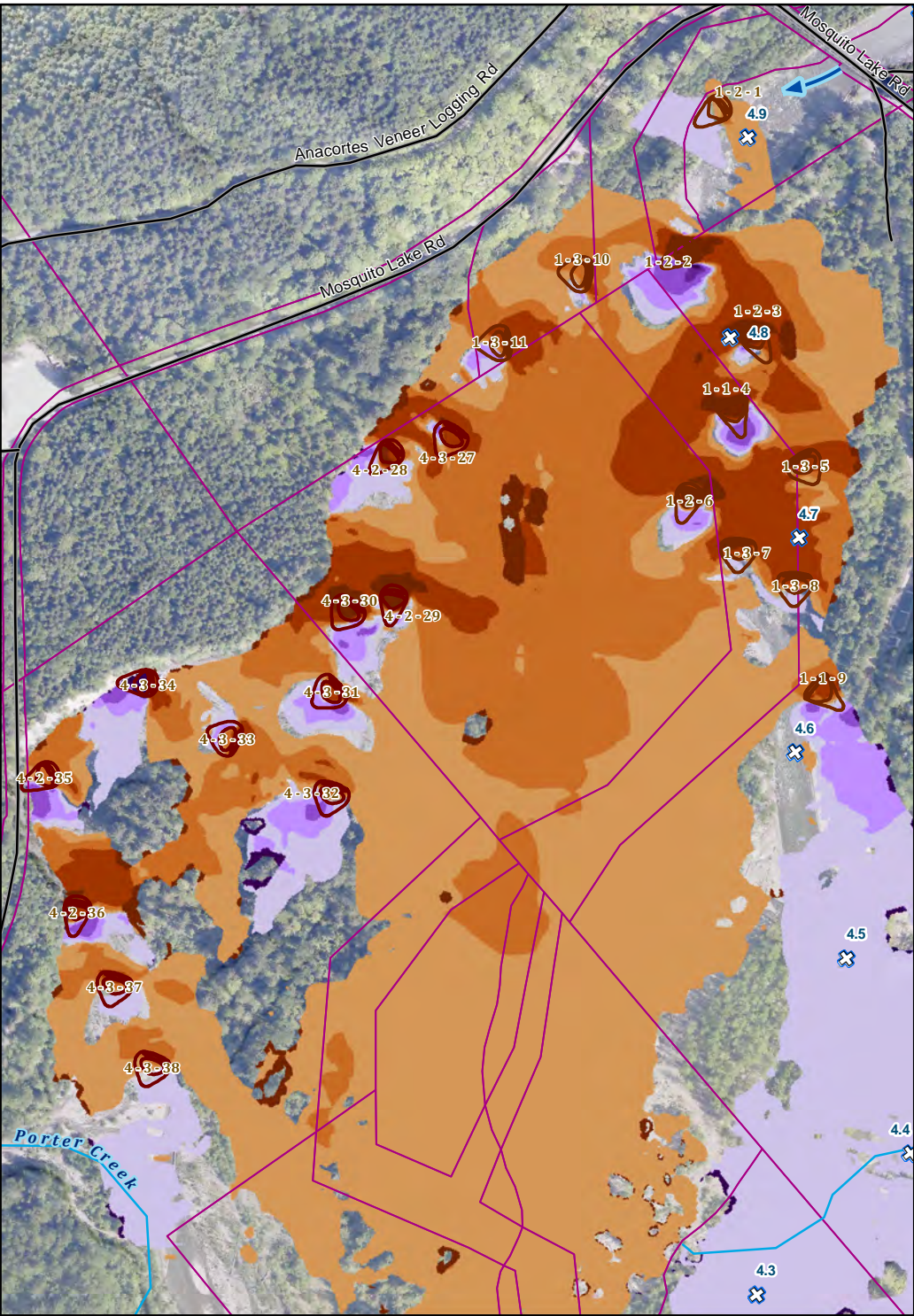
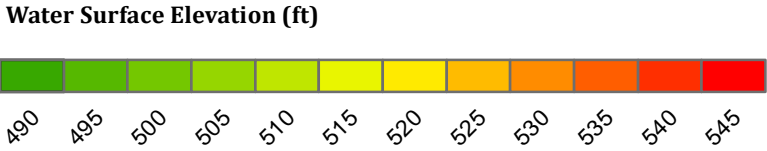




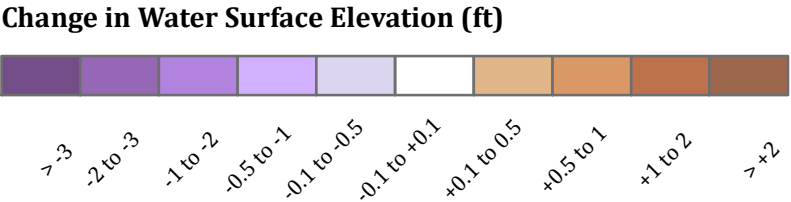
Existing Conditions



Proposed Conditions



Difference



Middle Fork Nooksack River - Porter Creek Reach Restoration Phase 1  
**Figure 8 - 100 year Flow Water Surface Elevation (26,000 cfs)**

Hydronia RiverFlo-2D Hydraulic Model Output for 100 year (26,000 cfs) flow event.  
Terrain used in hydraulic modeling is representative of 2013 conditions.

Parcels: Whatcom County 2013  
Roads: US Census Bureau 2010  
Streams: USGS NHD (1:24,000)  
River Miles: USGS Topo  
Aerial: USDA NAIP 2013

- 15 River Mile Streams
- Roads
- Parcel Boundaries
- Proposed ELJ



0 500 1,000 1,500 Feet  
Lambert conformal conic projection, NAD 1983  
State Plane Coordinate System (WA North Zone)







## APPENDIX A

### Preliminary Design Drawings



1900 N. Northlake Way, Suite 211  
Seattle, WA 98103



## APPENDIX B

### Cost Estimate



1900 N. Northlake Way, Suite 211  
Seattle, WA 98103

# **COST ESTIMATE**

Natural Systems Design

**Project:** MIDDLE FORK NOOKSACK LWD DESIGN PHASE 1

**Analyst:** G. Dooley

**Project No:** LNRD-006

**Checked:** 0

**Latest Revision:** 5/6/2016

**Allowance for Indeterminates Included in Bid Items:** 15%

**Inflation to 2016 \$ Included in Bid Items:** 4%

Item #	Item Description	Quantity	Unit	Unit Price (\$)	Amount (\$)
1	Mobilization, 10% Max	1	LS	\$63,608	\$63,608
2	Temporary Access Road	1	LS	\$5,950	\$5,950
3	Temporary Access Bridge	2	EA	\$5,950	\$11,900
4	TESC Measures	1	LS	\$5,950	\$5,950
5	Dewatering, Diversion	1	LS	\$15,470	\$15,470
6	Type 1 ELJ	2	EA	\$80,115	\$160,231
7	Type 2 ELJ	4	EA	\$61,747	\$246,988
8	Type 3 ELJ	5	EA	\$36,919	\$184,593
9	Roadside Cleanup	1	FA	\$5,000	\$5,000
	Construction Sub-Total				\$699,691
	Taxes (as % of Construction Sub-Total)	8.0%			55,975
<b>Total Estimated Construction Cost</b>					<b>\$755,666</b>

# **COST ESTIMATE**

Natural Systems Design

**Project:** MIDDLE FORK NOOKSACK LWD DESIGN PHASE 4

**Analyst:** G. Dooley

**Project No:** LNRD-006

**Checked:** 0

**Latest Revision:** 4/11/2016

**Allowance for Indeterminates Included in Bid Items:** 15%

**Inflation to 2016 \$ Included in Bid Items:** 4%

Item #	Item Description	Quantity	Unit	Unit Price (\$)	Amount (\$)
1	Mobilization, 10% Max	1	LS	\$59,299	\$59,299
2	Temporary Access Road	1	LS	\$5,950	\$5,950
3	TESC Measures	1	LS	\$5,950	\$5,950
4	Dewatering, Diversion	1	LS	\$8,925	\$8,925
5	Type 2 ELJ	5	EA	\$61,747	\$308,735
6	Type 3 ELJ	7	EA	\$36,919	\$258,431
7	Roadside Cleanup	1	FA	\$5,000	\$5,000
	Construction Sub-Total				\$652,290
	Taxes (as % of Construction Sub-Total)	8.0%			52,183
<b>Total Estimated Construction Cost</b>					<b>\$704,473</b>